Rail Accident Report

Collision between two passenger trains near Talerddig, Powys
21 October 2024

Report 08/2026
June 2026

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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Any enquiries about this publication should be sent to:

RAIB
The Wharf
Stores Road
Derby UK
DE21 4BA

Email: enquiries@raib.gov.uk
Telephone: 01332 253 300
Website: www.raib.gov.uk

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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 between two passenger trains near Talerddig, Powys, 21 October 2024

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Summary

At around 19:26 on Monday 21 October 2024, train reporting number 1J25, the 18:31 service from Shrewsbury to Aberystwyth, collided with train 1S71, the 19:09 Machynlleth to Shrewsbury service. The collision took place near Talerddig, Powys. Both train services were operated by Transport for Wales Rail Limited (TfWRL).

The trains were operating on Network Rail's Cambrian lines. This is predominantly single track, with passing loops provided at intervals to allow trains travelling in opposite directions to pass each other. Train 1J25 had been approaching the loop at Talerddig, with an intended stopping position within the loop, so that train 1S71 could pass it. However, train 1J25 did not stop as intended, continuing through the passing loop and into the single line section on which train 1S71 was approaching.

The head-on collision occurred while train 1J25 was travelling at approximately 39 km/h (24 mph) and train 1S71 was travelling at approximately 11 km/h (6 mph) in the opposite direction. At the point where the collision occurred, train 1J25 had travelled around 1,080 metres beyond its intended stopping position.

A passenger travelling on train 1J25 suffered fatal injuries as a consequence of the collision. Three people on this train were also seriously injured, including the train's guard, and 18 other people received minor injuries. The driver of train 1S71 suffered serious injuries, and the remaining five people on this train all suffered minor injuries.

Neither train derailed, but extensive damage was caused to both trains. Damage was also caused to railway infrastructure in Talerddig loop. The railway remained closed until 28 October 2024.

RAIB's investigation found that the accident was caused by train 1J25 passing its authorised stopping position and entering the single line beyond, which was occupied by the approaching train 1S71.

Train 1J25 passed its authorised stopping position due to a combination of three factors. These were that the wheel-rail adhesion in the area approaching the Talerddig loop was low, although not exceptionally so for this area during October. In addition, the two sanding systems fitted to train 1J25 which could have mitigated the prevailing low adhesion conditions, and avoided the accident, did not dispense sand. The automatic sander did not function, probably due to the presence of electrical faults in its control circuit, while the manually operated emergency sander was not activated by the driver. The third factor was that the approach speed of train 1J25 towards the eastern entry to Talerddig loop was such that the deceleration required to slow the train for the loop could not be sustained with the available wheel-rail adhesion.

Having passed its intended stopping position within Talerddig loop, train 1J25 entered the single line beyond. This area had exceptionally low wheel-rail adhesion and was on a steep downhill gradient. This meant that, even though the brakes on train 1J25 remained applied, the train did not decelerate as it approached train 1S71. There were no engineered mitigations to prevent train 1J25 entering the occupied single line in the event of an overrun.

The investigation identified a number of factors which affected the consequences of the collision for those involved. These were that train 1S71 was permitted to proceed to the end of its issued movement authority when it could have been brought to a stand by means of an railway emergency call from the driver of train 1J25 or an instruction from the signaller. Bringing train 1S71 to a stand would not have prevented the collision, as train 1J25 would have continued moving at a relatively constant speed down the descending gradient. However, had train 1S71 been stationary at the time of the collision, the collision energy would have been reduced.

A traction gel applicator, located on the railway to the west of Talerddig loop, was also not operational. This is a possible factor affecting the consequences of the accident, because this also had the potential to reduce the collision speed. Similarly, the decision to utilise the railhead treatment train for water jetting only, without applying an adhesion modifier, may have influenced the overrun, although it has not been possible to quantify this.

There was a loss of cab survival space on train 1S71. The design of the saloon tables on the trains involved in this accident was such that fatal injuries were caused to a passenger who collided with a table during the collision. There was also a loss of a viable egress route for some passengers due to jammed internal sliding doors and other vehicle damage. Fallen ceiling panels and opened equipment cupboard doors impeded access to the train by emergency services in the immediate aftermath of the accident.

RAIB's investigation found four underlying factors. One possible underlying factor was that there was a longstanding misalignment between the system safety models used for the Cambrian European Rail Traffic Management System (ERTMS) signalling system and class 158 rolling stock. The signalling system safety model was based on the premise that trains would deliver a predictable braking rate, regardless of prevailing wheel-rail adhesion conditions. The nature of the signalling system, which includes continuous supervision of the train's movement, permitted the use of reduced safety margins and hence increased the reliance on the integrity of the train's sanding systems. RAIB found no evidence that this increased reliance was recognised by any of the railway companies directly involved in the accident.

A second underlying factor was that TfWRL's processes intended to ensure the operation of the automatic sanding system were not sufficiently effective. TfWRL routinely used a test button to validate the operation of the system, with more in-depth checks carried out periodically. However, this accident showed that dormant and/or intermittent electrical failures could still exist despite the use of the sander test button to successfully discharge sand from the delivery hoses. This gave false assurance that the automatic sanding system would function in operational circumstances. This was not understood by TfWRL before the accident and, as a result, its processes were not sufficiently effective in ensuring that the automatic sanders of train 1J25 would work when required.

A probable underlying factor was that TfWRL had an incomplete understanding of the signalling system used on the Cambrian lines and its drivers' interactions with it. Had TfWRL had a better understanding of this, it may have understood that drivers were experiencing interventions from the signalling system more often than originally believed and that upcoming speed restrictions could be temporarily masked from drivers.

A further possible underlying factor was that TfWRL's training and competency management of its drivers did not equip them to deal with emergency situations like the one the driver of train 1J25 found themself in when approaching Talerddig on 21 October 2024.

A possible underlying factor relating to the severity of the accident's consequences was Network Rail's lack of a detailed understanding of the effectiveness of wheel-rail adhesion modifiers.

RAIB made three safety observations. Firstly, Network Rail had no formal competency framework for its seasonal delivery staff. Secondly, some members of TfWRL staff had received no training on the emergency equipment provided on the train. Finally, RAIB observed that low sand delivery rates can reduce the potential benefits provided by trainborne sanding systems.

As a result of the investigation, RAIB has made nine recommendations:

- Two recommendations are made to the Rail Safety and Standards Board and Angel Trains to improve the design, maintenance and testing of trainborne sanding equipment.
- A recommendation is made to Network Rail to review the assumptions made to justify the use of simple assessments of overrun risk on the Cambrian lines, considering the circumstances of this accident, and updated industry standards.
- A recommendation is made to Network Rail to improve overrun protection in future versions of software-based train control systems and for it to review how overrun risks are assessed, considering the circumstances of this accident.
- A further recommendation is made to Network Rail to improve wheel-rail adhesion conditions through the application of an improved understanding of the effectiveness of railhead treatment regimes. This builds on a previous RAIB recommendation following the 2021 accident at Salisbury.
- Two recommendations are made to TfWRL to ask it to review how drivers are trained, based on issues identified in this investigation.
- A recommendation is made to the Rail Safety and Standards Board to review standards and rules governing the design of passenger train interior fittings to reduce the risk to passengers in the event of an accident.
- A recommendation made to TfWRL intends that all on-train staff, irrespective of role have the skills and knowledge required to assist in the event of an emergency.

RAIB also identified a learning point relating to reaching a clear understanding when safety-critical communications take place between signallers and train drivers.

Introduction

Definitions

1 Metric units are used in this report. Unlike most of the British mainline railway, speeds on the Cambrian lines use metric units. Imperial equivalents are provided where it may aid understanding.

2 Most figures in this report, other than maps which are traditionally orientated with north at the top, show Shrewsbury to the left and Machynlleth to the right. This is to ensure consistency between the various charts presented in this report and the zero-point for distances for the Cambrian lines which is located near Shrewsbury (see paragraph 14).

3 The report uses data obtained from several different recording devices which do not share the same time source. To allow a timeline of the accident events to be constructed, RAIB has synchronised all event recordings to one time source, the time used by the signalling system. It is this corrected time which is quoted throughout this report. Due to the way some data recorders function, short delays (typically less than a second) can elapse between an event occurring and the recording device logging that change. Event timings should therefore be considered as having a small degree of uncertainty, even if quoted to single tenths of a second.

4 The report contains abbreviations and acronyms which are explained in appendix A. Sources of evidence used in the investigation are listed in appendix B.

The accident

Summary of the accident

5 At around 19:26 on Monday 21 October 2024, train reporting number 1J25, the 18:31 passenger service from Shrewsbury to Aberystwyth, collided with train reporting number 1S71, the 19:09 Machynlleth to Shrewsbury passenger service. Both services were operated by Transport for Wales Rail Limited (TfWRL).

6 The collision took place on Network Rail's Cambrian lines to the west of the passing loop located at Talerddig, Powys, (figures 1 and 2). From both directions, the railway approaching Talerddig loop consists of a single line. Train 1J25, travelling west, was due to stop in the loop to allow eastbound train 1S71 to pass it. Train 1J25 was braking as it approached and was passing through the loop. Despite braking, it was unable to stop within the loop as intended. The train subsequently exited the loop while still braking, and entered the single line, heading towards train 1S71. Train 1J25 travelled approximately 1,080 metres beyond its intended stopping position, before colliding with train 1S71.

7 At the time of the collision, train 1J25 was travelling at approximately 39 km/h (24 mph), while train 1S71 was travelling in the opposite direction at approximately 11 km/h (6 mph).

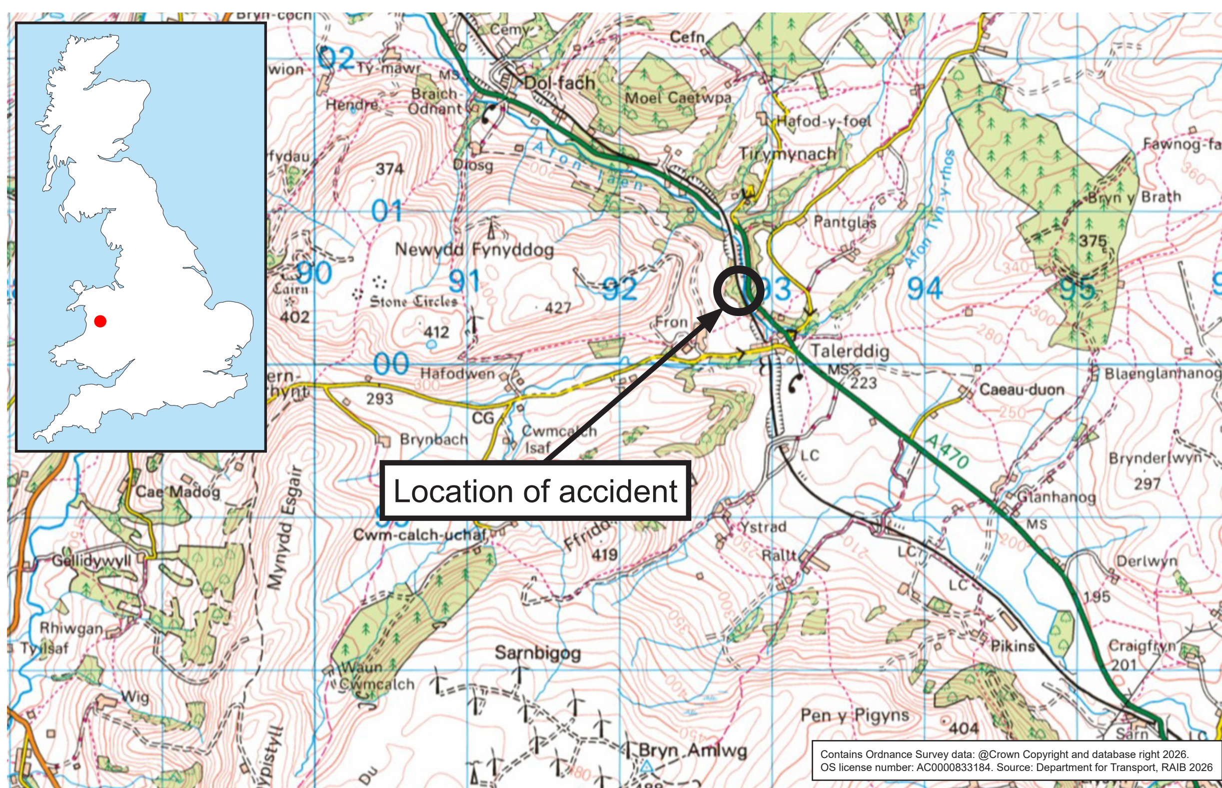

Figure 1: Extract from Ordnance Survey map showing location of the accident at Talerddig.

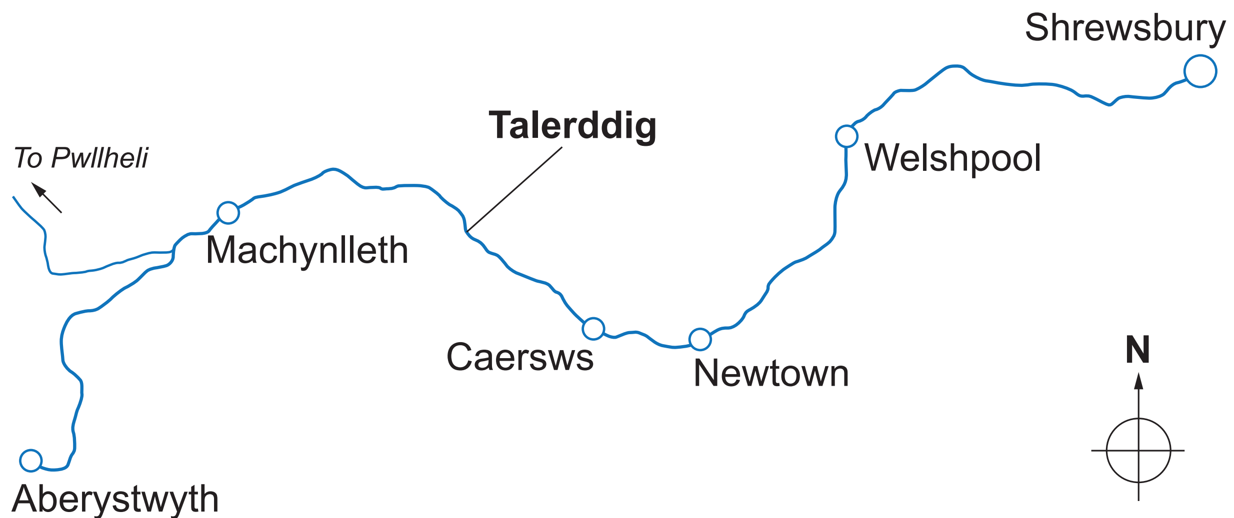

Figure 2: Overview of site showing geographical relationship of main features.

8 There were 31 people on board train 1J25, including the train driver, the guard and one other member of TfWRL staff.

9 A passenger on 1J25, Mr Tudor Evans, died as a consequence of the collision. Three people were seriously injured, including the train's guard. RAIB has been able to confirm that a further 18 people received minor injuries. The nine remaining passengers have either reported suffering no injuries or RAIB has been unable to obtain information from them about any possible injuries.

10 There were six people on board train 1S71, including the train driver and the guard. The driver of this train was in the process of attempting to leave the driving cab when the collision occurred, almost certainly in response to seeing the approaching headlights of train 1J25. The driver became trapped during the collision and was seriously injured. The remaining five people on board reported minor injuries.

11 The leading ends of each train (vehicle 57841 of train 1J25 and vehicle 57824 of train 1S71) suffered damage in the collision (figure 3). The driving cab of train 1S71 received the most damage and was significantly deformed. The basic structural integrity of the passenger compartments on each train was maintained although a number of internal panels became displaced, and some internal and external doors became inoperable. Underframe equipment on both trains was displaced but did not become detached.

12 During the accident, train 1J25 ran through a set of points at the west end of the loop, which were not set for its route. The points were damaged and needed repair. There was no other significant damage caused to the infrastructure. The line was reopened on 28 October 2024, 7 days after the accident.

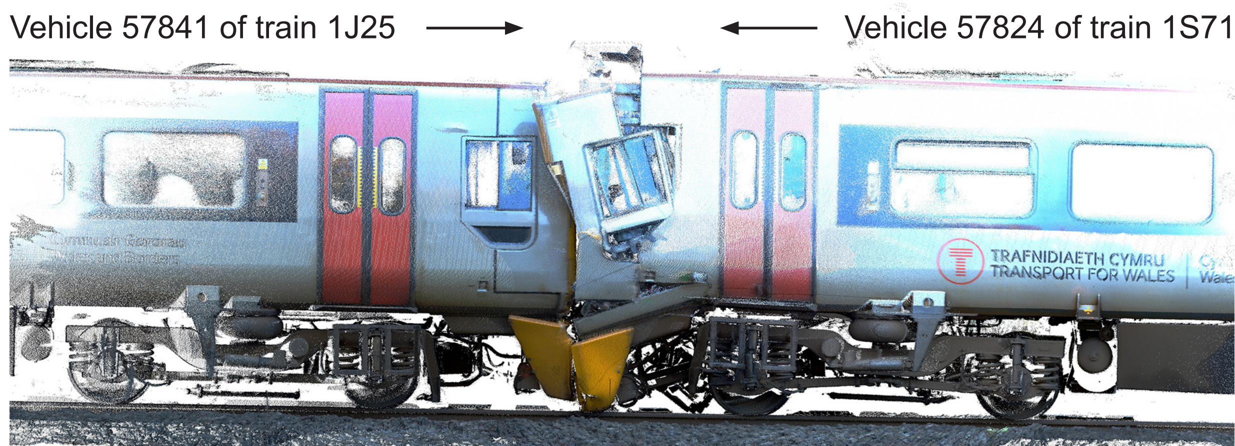

Figure 3: Side view of the collision showing the leading vehicle of each train (image created from laser scans).

Context

Location

13 The accident occurred on the Cambrian lines which runs from Shrewsbury to Aberystwyth and Pwllheli, passing over the Cambrian Mountains in central Wales. The route includes long sections of single line railway, with passing loops provided at certain locations to allow trains moving in opposite directions to pass each other.

14 The accident occurred near Talerddig loop (figure 4). This loop is located at 61 miles and 26 chains, measured from a datum point at Whitchurch via Oswestry.[1] The signalling system on the Cambrian lines uses metric distances and the loop is located a distance of 74.511 km from a datum point at Sutton Bridge Junction (located near Shrewsbury).

15 Trains can be signalled into either side of the loop, at the discretion of the signaller located at Machynlleth. The points at each end of the loop are conventional power-operated points, of the 'Clamplock' type. They are operated remotely by the signaller.

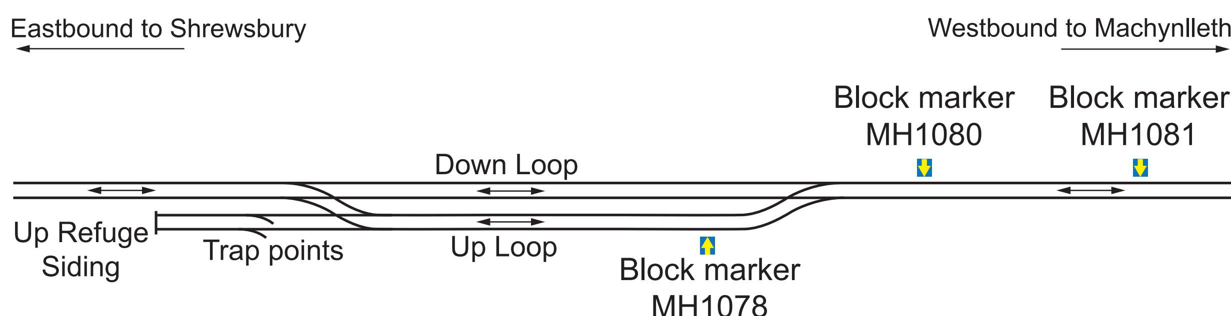

Figure 4: Talerddig loop (not to scale and not all equipment is shown).

[1] Via a now-closed railway from Oswestry to Buttington. Talerddig loop is 46 miles and 25 chains from Sutton Bridge Junction, located to the south of Shrewsbury station.

16 The permissible speed for trains approaching Talerddig in a westbound direction (such as train 1J25) is 130 km/h. This reduces on the approach to the passing loop, initially to 115 km/h and then to 95 km/h. The permissible speed then further reduces to 50 km/h for trains entering the Up Loop (figure 5). For trains passing via the Down Loop in a westbound direction, the permissible speed is 95 km/h.

17 The permissible speed for trains approaching Talerddig in an eastbound direction (such as train 1S71) is 95 km/h on the approach to the loop. This then reduces to 50 km/h for trains entering the Up Loop. For trains passing via the Down Loop in an eastbound direction, the permissible speed is 95 km/h.

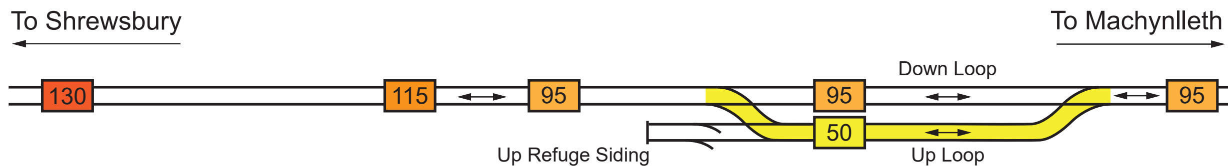

Figure 5: Permissible speeds around Talerddig: yellow highlight shows the extent of the 50 km/h speed restriction through the Up Loop.

18 The loop at Talerddig is located on a summit with an ascending gradient for westbound trains (such as train 1J25) approaching it. The exit from the passing loop for westbound trains, travelling towards Machynlleth, descends to the collision point (figure 6).

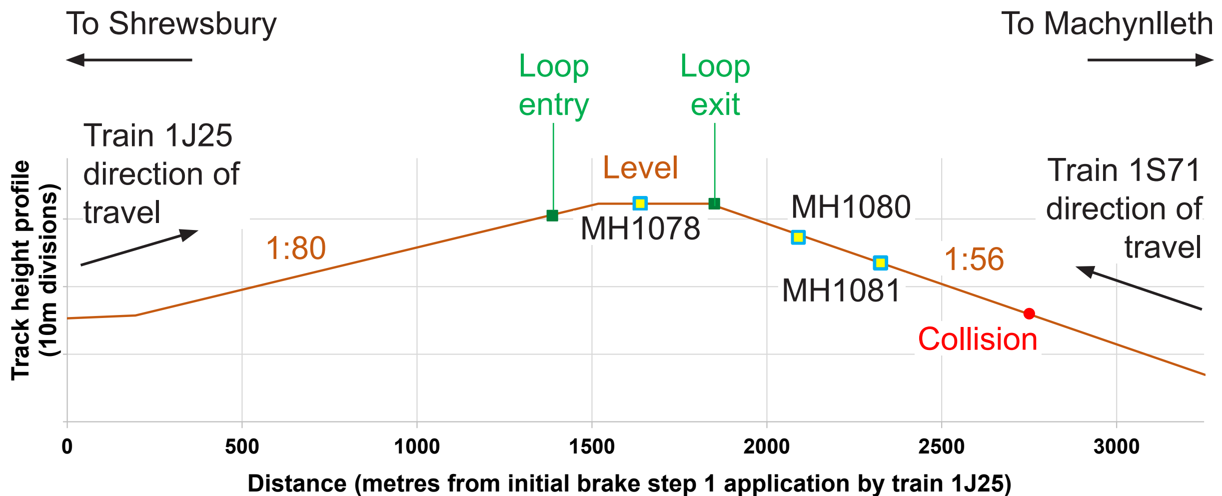

Figure 6: Average track gradient and features at Talerddig loop.

Organisations involved

19 The railway infrastructure at Talerddig is owned, managed and maintained by Network Rail. It forms part of Network Rail's Wales and Borders route which, along with the Western route, forms the Wales & Western region. Each Network Rail region acts as a devolved management organisation within the company.

20 Network Rail employs the signallers at Machynlleth signalling centre and a seasons delivery manager (SDM) responsible for seasonal preparations (appendix E). Network Rail also employs the staff responsible for maintenance of the infrastructure at Talerddig, lineside vegetation management and trackside equipment maintenance.

21 TfWRL operated both train services involved. TfWRL has operated most rail services in Wales, including the Cambrian lines, since February 2021. TfWRL employs the train drivers, the guards of both trains and the customer host who was travelling on train 1J25.

22 All the rail vehicles involved are owned by Angel Trains and leased to TfWRL.

23 Ansaldo STS (now Compagnie des Signaux) supplied the equipment for the Cambrian European Rail Traffic Management System (ERTMS) installation (see paragraph 31) and provides technical support to the local Network Rail signalling maintenance staff when requested.

24 All parties freely co-operated with RAIB's investigation.

Railway systems and infrastructure involved

Class 158 trains

25 Both trains involved in the accident were class 158 diesel multiple units. An example of a class 158 unit is shown in figure 7, and a schematic of the vehicle and unit numbers is shown in figure 8.

Figure 7: Class 158 unit.

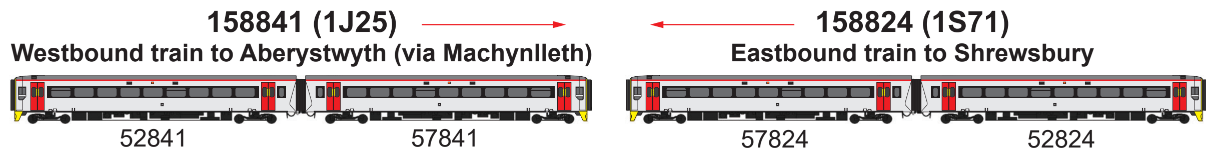

Figure 8: Formation and direction of travel of trains 1S71 and 1J25.

26 Train 1J25, was formed of unit number 158841. This comprised vehicle 57841 (leading) and vehicle 52841 (trailing).

27 Train 1S71, was formed of unit number 158824. This comprised vehicle 57824 (leading) and vehicle 52824 (trailing).

28 At the time of the accident TfWRL operated a fleet of 24 class 158 units. Each of these units is formed of two individual vehicles. The units are manually driven and are fitted with the necessary equipment to allow them to operate under the supervision of the Cambrian lines ERTMS system (see paragraph 31). The modification to install the ERTMS system to the class 158 units was carried out when the Cambrian lines were operated by a previous train operator, Arriva Trains Wales.

29 TfWRL carries out all routine maintenance on the trains involved, predominantly at its depot at Machynlleth. Examination of the maintenance records for the trains involved showed that the trains were compliant with their defined maintenance plan, with no recorded defects relevant to the accident.

30 Class 158 units were built between 1989 and 1992. This type of unit is widely used in the UK by a number of train operators. Constructed mostly from aluminium extrusions, each vehicle is fitted with a diesel engine which drives two wheelsets on one of the vehicle’s bogies. The other bogie on each vehicle is not powered. These units are fitted with a three-step braking system (see paragraph 85). Step 1 provides the lowest level of braking, while step 3 (known as ‘full service braking’) provides the maximum braking effort.

Signalling system

31 The Cambrian lines has operated since 2011 under the control of an ERTMS signalling system. The Cambrian lines ERTMS system was a pilot installation and was intended as an early deployment scheme which would provide Network Rail with experience of ERTMS operations ahead of its more widespread implementation on other parts of the mainline network. The Cambrian lines ERTMS system is controlled from a signalling centre in Machynlleth and replaces traditional lineside signals and signs with ‘movement authorities’ transmitted by radio to trains. A movement authority is the electronic permission for a train to occupy a section of track, or block section. Each block section on the Cambrian lines is denoted by a lineside sign known as a block marker. Equipment on board the train continuously supervises the speed and location of the train and will intervene, with a brake application, if the train is travelling too fast or is likely to exceed its movement authority.

32 ERTMS is based on a suite of unified standards which, in the simplest terms, is intended to allow interoperability between signalling systems and trains crossing international borders. Signalling system suppliers design their products to comply with these standards and interface with the local infrastructure. The Cambrian lines ERTMS installation was designed to operate with level 2 of the European Train Control System (ETCS), which is defined in the Control Command and Signalling Technical Specification for Interoperability (CCS-TSI).

33 The Cambrian installation consists of two major components. ETCS provides the signalling and train supervision function and the Global System for Mobile communications for Railways (GSM-R), provides the radio system which allows data and voice communications between the train and lineside infrastructure. ERTMS also required trains to be fitted with a means of recording data about the train and information passed between it and the signalling system. To meet this requirement, the TfWRL units were fitted with a recorder known as the Juridical Recording Unit (JRU). For the class 158 units operating on the Cambrian lines, one JRU is provided for each two-car unit in addition to the on-board data recorder provided on each vehicle of the class 158 units in common with those operating on other parts of the railway network.

34 ETCS monitors different inputs to establish the speed of the train. This data allows the on-board system to determine the distance the train has travelled and calculate its location on the railway. Transponder beacons installed at fixed locations on the track, known as 'balises', allow the on-board equipment to confirm its location and to reset any error arising from the speed/distance calculation.

35 A screen in the cab (figure 9), known as the Driver-Machine Interface (DMI), provides information to the driver. This information includes the limits of the current movement authority and the maximum permissible speed of the train. A 'planning area' shown on the DMI gives the driver advance warning of forthcoming speed restrictions.

Staff involved

36 The driver of train 1J25 was certified as competent to drive class 158 units on the Cambrian lines in March 2022. Before that, they had worked in other roles in the rail industry for 13 years. All the driver's competence assessments were in date in accordance with TfWRL's train driver competency management process.

37 The driver of train 1S71 had worked in the rail industry since 1997, including extended periods as a driver for other operators. They were certified as competent to drive class 158 units on the Cambrian lines in May 2023. All the driver's competence assessments were in date in accordance with TfWRL's train driver competency management process.

38 Both trains also carried a guard, and train 1J25 additionally carried a customer host. All the on-board staff were employed by TfWRL and held the necessary competencies for their respective roles.

39 The signaller at Machynlleth signalling centre, controlling this part of the route at the time of the accident, held all the necessary competencies for that work. The signaller had 8 years' experience and had worked at Machynlleth signalling centre for 7 of those years. All the signaller's competence assessments were in date in accordance with Network Rail's competency management process.

Figure 9: The driver's desk in a class 158 train.

External circumstances

40 Analysis of rainfall radar imagery shows there was light rainfall in the Talerddig area shortly before the accident. This is discussed further at paragraph 116. Sunset occurred just after 18:00, so it was dark at the time. The area around Talerddig is rural and sparsely populated. Consequently, there is very little ambient light at night.

The sequence of events

Events preceding the accident

41 During the night of 19 to 20 October 2024, unit 158841, which eventually formed train 1J25, underwent a fuel point examination at TfWRL's Machynlleth depot. This is a routine maintenance activity which is carried out approximately every 1,500 miles (2,400 km) and includes refuelling the train and carrying out checks on safety equipment, including the train's automatic sanders. To check the automatic sanders, a maintenance technician presses a sander test button (see paragraph 161) and observes if sand is ejected from the sand hoses. The sander test button is mounted on the sand hopper, which is on the train's underframe. Witness evidence indicates that the test was carried out, and the train was seen to discharge sand as expected.

42 Before entering service on the morning of 20 October, unit 158841 was prepared by a driver instructor and a trainee driver. This preparation included internal and external inspections of the train, together with further checks of the functionality of safety systems, including the train's automatic sanders. This check is also carried out by pressing the sander test button (figure 17) and checking that sand is discharged. Witness evidence indicates that this preparation was carried out and that the train again discharged sand when the test button was pressed.

43 During 20 October, unit 158841 was operated on various routes to Aberystwyth, Shrewsbury, Birmingham and Chester. After the last passenger service finished at Shrewsbury, unit 158841 was planned to be stabled overnight at Crewe maintenance depot. However, due to service disruption, the unit was instead driven to Chester (via Gobowen) arriving just before midnight, where it was then stabled in a station platform overnight. TfWRL informed RAIB that the overnight stabling of units within platforms is allowed within its relevant operating processes.

44 Network Rail's Rail Head Treatment Train (RHTT, see paragraph 135) treated the line through Talerddig in accordance with its planned schedule on the evening of 20 October 2024. This treatment included the single lines around Talerddig and both tracks at the passing loop. The railhead treatment used on the Cambrian lines involves water jetting, without the use of an adhesion modifier (see paragraph 140).

45 Early on the morning of 21 October, a driver prepared unit 158841 for service. However, the unit was positioned adjacent to one of the platforms at Chester station and this meant that the driver concerned did not have access to equipment on the train's underframe, including the sander test button. Consequently, this driver was unable to, and was not required to, check the operation of the automatic sanding system.

46 After the train had been prepared, unit 158841 entered service and made various journeys between Aberystwyth, Shrewsbury and Birmingham. Several of these journeys were operated from the cab of vehicle 57841. The train was driven by various drivers, and no defects were reported during this time.

47 The seventh journey for unit 158841 on 21 October was as train 1D16, the 17:08 service from Birmingham International to Shrewsbury and Llandudno. This train was formed of unit 158841, coupled to another TfWRL unit, 158828. The cab of vehicle 57841 was trailing for the first leg of the journey to Shrewsbury. On arrival at Shrewsbury, the units were uncoupled, with unit 158828 continuing as train 1D16 to Llandudno, while unit 158841 formed train 1J25 from Shrewsbury to Aberystwyth. The track layout at Shrewsbury meant that the unit needed to reverse direction so train 1J25 was operated with the cab of vehicle 57841 leading the train.

48 The driver of train 1J25 took over the train at Shrewsbury. It departed 2 minutes late at 18:33, and then called at Welshpool, Newtown and Caersws stations, departing from each on time. Examination of data drawn from the train's on train data recorder (OTDR, sometimes called 'the black box') shows that the train did not encounter conditions which would have resulted in the automatic sanding system activating during this period. The train departed from Caersws at 19:15 with the next scheduled station stop due to be Machynlleth, at 19:45.

49 Train 1S71, operated by unit 158824, departed from Machynlleth at 19:08. The timetable dictated that train 1S71 would pass train 1J25 at Talerddig loop. As both trains were running on time, there was no reason to vary from this plan. Both train drivers were expecting to pass another train at Talerddig.

50 In Machynlleth signalling centre, the signaller's intended operation of the passing loop at Talerddig on this occasion could be summarised in three steps (figure 10):

a. Westbound train 1J25 would arrive first, be signalled into the Up Loop and stop at block marker MH1078.

b. Eastbound train 1S71 would arrive next, be signalled via the Down Loop and pass through without stopping.

c. Westbound train 1J25 would then be signalled back onto the single line.

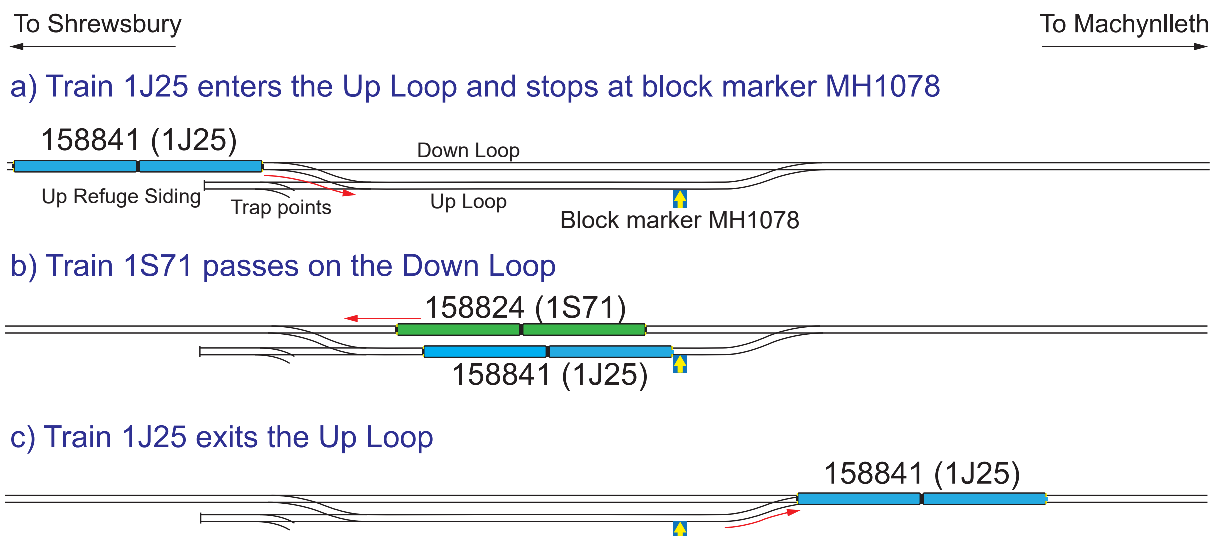

Figure 10: The intended sequence of events at Talerddig loop (not to scale).

51 The signaller chose this sequence of operations so that the eastbound train (1S71), which was climbing the steeper gradient on the approach to the loop (figure 6), would pass through the Down Loop, which has a higher permissible speed (95 km/h) than the Up Loop (50 km/h).

Events during the accident

52 A simplified sequence of events is shown in figure 11. At approximately 19:22, train 1J25 approached Talerddig loop from the east. Data from the OTDR of train 1J25 shows that the driver shut off traction power while the train was travelling at 125 km/h. At this point, the intended stopping position, at block marker MH1078, was approximately 1,900 metres away. Over the next 39 seconds, the driver made two separate step 1 brake applications to bring the train's speed down to 94 km/h. The train's brakes were released after each of these brake applications (figures 12 and 13).

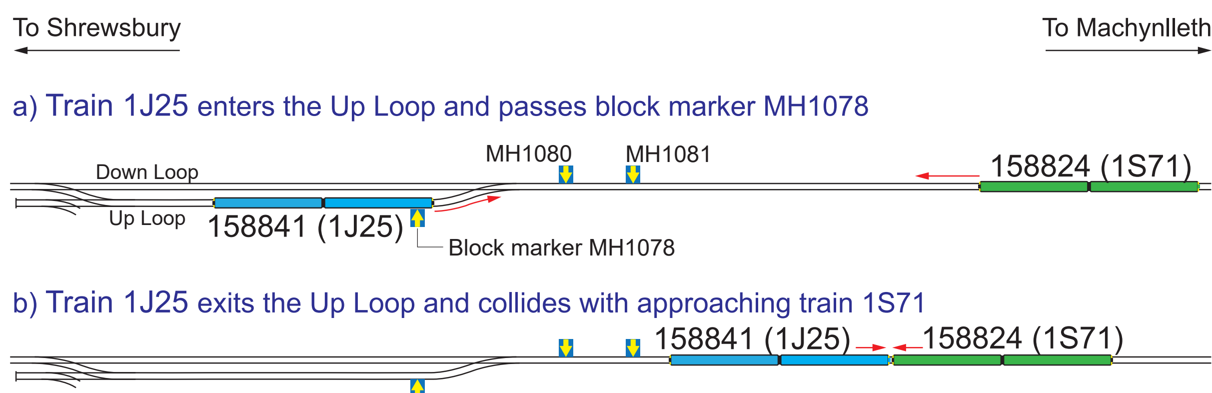

Figure 11: The simplified sequence of events at Talerddig loop (not to scale).

53 At approximately 19:23, the driver selected step 2 braking (figures 12 and 13). The intended stopping position was now approximately 730 metres away. Between 3 to 4 seconds later, an application of full service braking (step 3) was made when block marker MH1078 was approximately 640 metres away. The train had not yet reached the start of the passing loop. Data from the JRU shows that ETCS applied the full service brake automatically, although witness evidence indicates that the driver also made a full service brake application at approximately the same time. Limitations in the way the OTDR records data means it is not possible to confirm when the driver manually applied full service braking after the application had been made by the signalling system. RAIB has concluded from its analysis of OTDR data that the train's wheel slide protection (WSP) system (see paragraph 88) intervened to control wheel rotation approximately 1 second after the full service brake application.

54 After about 6 seconds of full service braking, with train 1J25 travelling at approximately 80 km/h, the on-board signalling system intervened with an emergency brake demand. On class 158 units, the emergency brake provides the same level of braking force as the full service brake (see paragraph 86). The intended stopping position was now approximately 500 metres away.

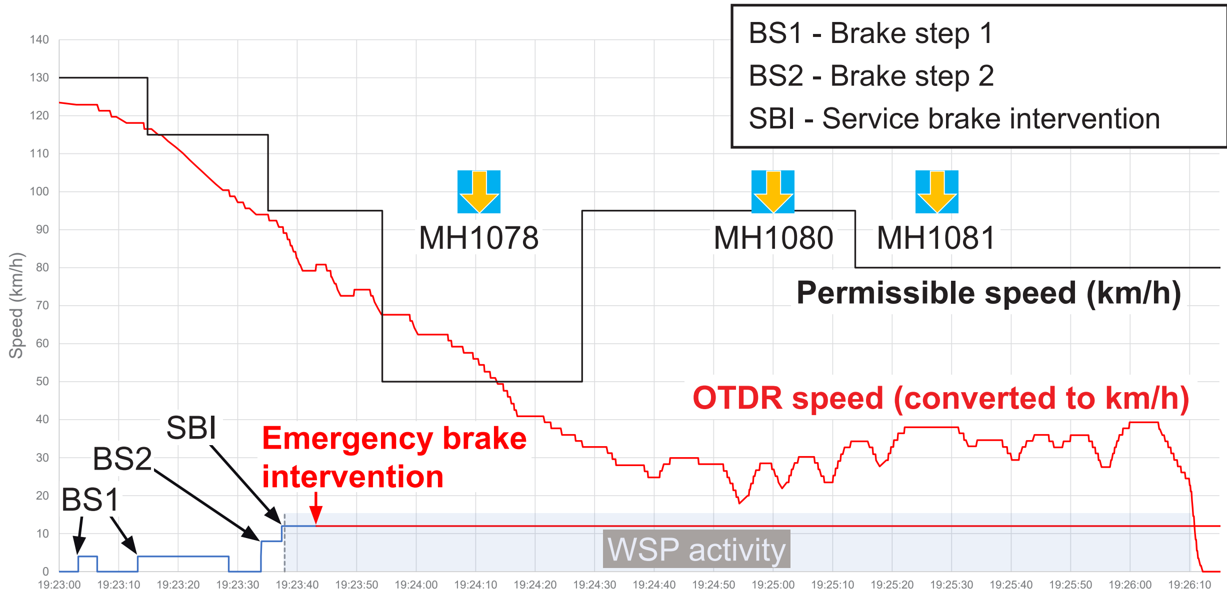

Figure 12: Data from the OTDR on train 1J25, showing braking profile, speed and block marker locations.

Point of collision
39 km/h

MH1078
54 km/h

Talerddig loop

Emergency brake intervention
80 km/h

Brake step 2
94 km/h

Service brake intervention / Brake step 3
91 km/h

Brake step 1
start 118 km/h
end 100 km/h

Brake step 1
start 123 km/h
end 123 km/h

Direction of travel

Figure 13: The sequence of brake applications made by train 1J25 overlaid on the geography of the area around Talerddig loop.

55 The driver of train 1J25 then used the train's GSM-R radio to call the signaller to report that the train was sliding and was probably going to pass block marker MH1078 (figures 14 and 15). Less than 20 seconds after starting the call, the train passed block marker MH1078 at approximately 54 km/h. The area beyond block marker MH1078 is an area designated as being at high risk of low adhesion (see paragraph 247).

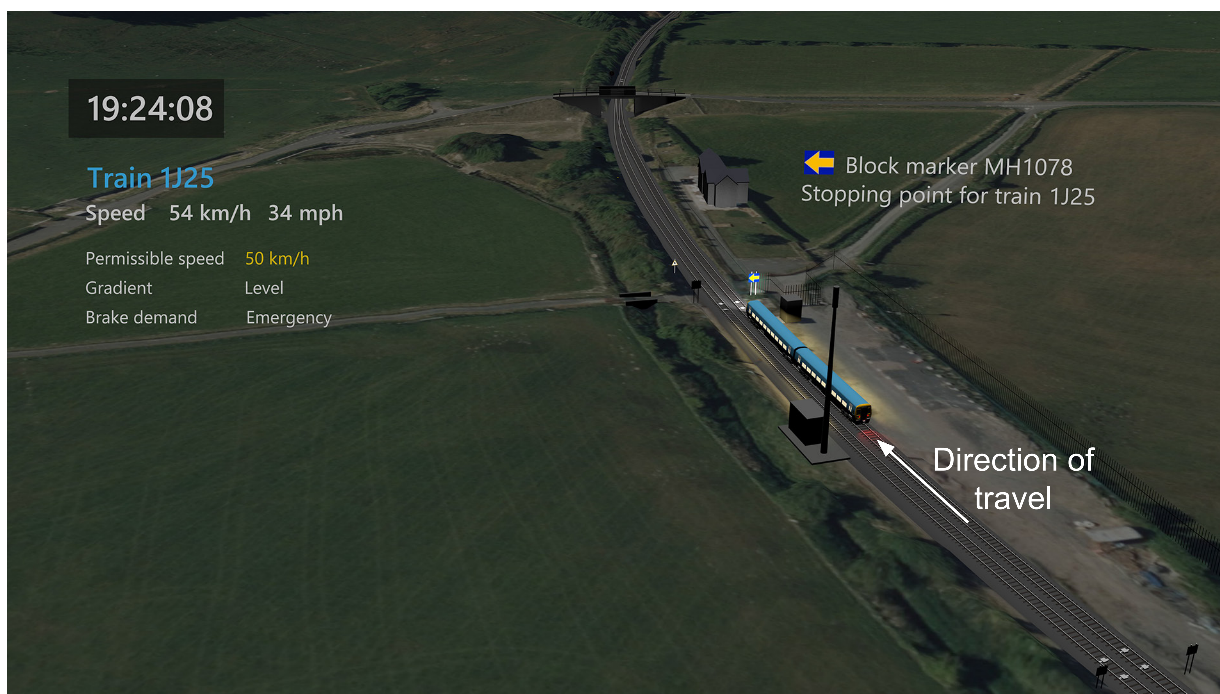

Figure 14: Extract from RAIB animation showing train 1J25 passing block marker MH1078.

Figure 15: The intended stopping position for train 1J25, at block marker MH1078 on the Up Loop. A low adhesion warning sign is also visible on the left side of the Down Loop.

56 At around 19:24, the call with the signaller ended, as the train ran through the points and exited Talerddig Up Loop at approximately 33 km/h. The distance from block marker MH1078 to the points is around 190 metres. Train 1J25 then entered the descending gradient on the single line. Although the unit's brakes remained fully applied, the train did not decelerate.

57 Train 1S71 was approaching Talerddig from the west. The train had been issued with a movement authority (paragraph 31) by the ETCS system which permitted the train to proceed to block marker MH1081 (figure 4).

58 After the call with the driver of train 1J25 ended, the Machynlleth signaller called the driver of train 1S71, stating that train 1J25 had passed block marker MH1078 and was occupying the loop exit points. The signaller instructed the driver of train 1S71 to continue but then stop at the end of the current movement authority, block marker MH1081. The driver of 1S71 mentioned that the train was struggling with low adhesion on the uphill gradient. At the end of the call, train 1S71 was travelling at 26 km/h. During this call, train 1J25 passed MH1080 (figure 4), the next block marker in that train's direction of travel.

59 While descending the gradient, the driver of train 1J25 called the train's guard using the train's internal cab-to-cab telephone system. The driver told the guard about the difficulty controlling the train and, in response, the guard left the rear cab to make their way to the front of the train. The driver, aware that a second eastbound train would be approaching in the opposite direction on the single line (paragraph 49), and that a collision was therefore imminent, left the cab. CCTV shows the driver moving into the saloon approximately 10 seconds before the collision, and shortly afterwards gave a verbal warning to nearby passengers in the leading vehicle.

60 Following the conversation with the signaller, the driver of train 1S71 shut off traction power and began to control the train to stop at MH1081. Around 9 seconds after speaking to the signaller, the driver applied the emergency brake and attempted to leave the cab. This took place about 3.7 seconds before the collision, almost certainly in response to seeing the approaching headlights of train 1J25.

61 The collision occurred at around 19:26, while train 1J25 was travelling at approximately 39 km/h (24 mph)[2] and train 1S71 was travelling at approximately 11 km/h (6 mph). At the point where the collision occurred, train 1J25 had travelled around 1,080 metres beyond block marker MH1078, and around 360 metres beyond block marker MH1081 (the position at which train 1S71 had been instructed to stop).

62 During the initial collision, train 1J25 lost a significant amount of its forward speed, and train 1S71 reversed direction. The two trains separated slightly and continued down the gradient. Approximately 5 seconds later, the two trains collided again, although there was considerably less energy in this second impact. The two trains then came to rest together approximately 35 metres from the location of the initial collision (figure 16).

[2] RAIB has derived the collision speed of 1J25 by cross-referencing OTDR and JRU data and comparing this with CCTV image timings.

Figure 16: The trains involved, showing the approximate location of the collision and the final resting position.

Events following the accident

63 Just over 2 minutes after the collision, the driver of train 1J25, having checked on the passengers and gone to the rear of the train, made a GSM-R railway emergency call (REC) to the signaller from the rear cab to report the collision and to request the attendance of the emergency services.

64 The first 999 call from the scene to the emergency services was made by the guard of train 1S71 who reported the accident to Dyfed Powys Police at 19:28. In turn, the Welsh Ambulance Service, the Mid and West Wales Fire Service, and British Transport Police (BTP) were also alerted. The guard of train 1S71 and the customer host of train 1J25 assisted passengers and staff after the accident and provided first aid to the injured.

65 At around 19:32, the Joint Rescue Co-ordination Centre – Aeronautical Rescue were informed of the accident by the Welsh Ambulance Service. It arranged for two HM Coastguard helicopters to collect Welsh Ambulance Service staff and convey them to the scene. Four fire appliances were sent from Newtown and Machynlleth fire stations with an appliance from Newtown being the first emergency service resource to arrive at 19:57. By 20:00, land ambulances had arrived, along with officers from BTP. Subsequently, arrangements were made for air ambulances to also attend to assist.

66 In line with standard rail industry procedures following an accident, the driver of train 1J25 provided screening samples which were tested for the presence of both alcohol and drugs; both tests were negative.

67 The driver of train 1S71 was taken to hospital and was not tested for alcohol and drugs because of their injuries. There is no evidence of the presence of drugs or alcohol in the driver of train 1S71.

Analysis

Background information

Wheel-rail adhesion

68 Trains rely on friction between their steel wheels and the steel railhead to accelerate and decelerate. The level of wheel-rail friction is therefore critical to safe train operation. The railway industry typically refers to this as ‘wheel-rail adhesion’. This phrase will be used throughout this investigation report except when referring to the technical parameter ‘coefficient of friction’ (see paragraph 74).

69 Research indicates[3] that wheel-rail adhesion can be significantly reduced by the presence of contamination and/or moisture on the railhead. When a train is braking and encounters a section of track with low adhesion, the brake force may exceed the available wheel-rail adhesion and the braking performance be consequently affected, and stopping distances extended.

70 In 1995, the rail industry established a cross-industry Adhesion Working Group (now part of the Seasonal Challenge Steering Group, whose remit includes other seasonal weather). The group’s objective was to research and develop initiatives to combat the effects of low wheel-rail adhesion. The group produces a manual called ‘Managing low adhesion’[4] which serves as a repository of knowledge for understanding and managing low wheel-rail adhesion.

71 Railhead contamination can come from a range of sources, but the most common cause is leaves falling onto the railhead and being compressed by train wheels, forming leaf layers which chemically bond to the rail. The rate at which leaf contamination builds up is dependent on a range of factors, including the number of trains that have passed over the location since the last railhead treatment (see paragraph 134), train braking, and the leaf fall within a given period. The rate of leaf fall is in turn affected by the environment, meteorological conditions, topography (such as cuttings and embankments) and tree species.

72 Besides leaf fall, low adhesion can also be caused by other contaminants such as corrosion products (rust), fuel, oil and grease. Railhead contamination is sometimes visible; for example, a black leaf film can sometimes be seen during autumn. However, not all contamination is visible to the human eye, and a very thin leaf film may not be visible but still cause low adhesion.

73 Moisture on the railhead can also sometimes cause low adhesion. The ‘Managing low adhesion’ manual defines a ‘wet rail phenomenon’, as ‘*poor adhesion conditions caused when low levels of moisture are present at the wheel-rail interface. These conditions are associated with dew on the railhead, very light rain, misty conditions, and the transition between dry and wet rails at the onset of rain*’.

[3] Rail Safety and Standards Board project T354, ‘The characteristics of railhead leaf contamination’, 2004.

[4] Seasonal Challenge Steering Group, ‘Managing Low Adhesion’ seventh edition, dated 2024.

74 The level of wheel-rail adhesion is normally expressed as a coefficient of friction (μ). Typical coefficient of friction values are included in the 'Managing low adhesion' manual and are reproduced in table 1. Adhesion levels can vary considerably over relatively short distances and timescales.

Adhesion level	Typical coefficient of friction (μ)	Description
High	>0.15	Clean rails wet or dry
Medium	0.10 to 0.15	Damp rails with some contamination
Low	0.05 to 0.09	Typical autumn mornings due to dew / dampness often combined with light overnight rust
Exceptionally Low	<0.05	Severe rail contamination often due to leaves but sometimes other pollution

Table 1: Range of railhead adhesion on the rail network as defined in 'Managing low adhesion' manual.

Sanding systems

75 The application of sand is a well-established mitigation for low wheel-rail adhesion conditions, and the use of trainborne sanders can help restore braking and traction performance. When needed, sand is dispensed from on-board sand boxes and delivered through flexible hoses aimed directly at the wheel-rail interface. Sand is considered to have two main benefits:

- providing a temporary boost to the level of adhesion experienced by the sanded wheelset (and, to a lesser extent, subsequent wheelsets)
- abrading or breaking down any railhead contamination (such as leaf film) and assisting in its removal.

76 Sand can be deployed when a prescribed set of conditions are met. These conditions usually include that the train is braking and has encountered low adhesion.

77 Most passenger trains which operate on the mainline railway in Great Britain are fitted with an on-board sanding system. Appendix C provides further information on the standards which are applicable to sanding systems.

Sanding systems as fitted to TfWRL class 158 units

78 The class 158 units operated by TfWRL are fitted with two separate and independent sanding systems; these are an automatic sanding system and an emergency one-shot sanding system.

79 Class 158 units were built between 1989 and 1992 (paragraph 30). As was common with trains built at that time, no sanding systems were originally fitted. However, shortly after their introduction into service, problems were encountered with the trains' performance in conditions of low wheel-rail adhesion. Consequently, a need to fit sanding systems was recognised. An emergency one-shot sanding system (see paragraph 193) was therefore developed and fitted to the leading wheelsets of class 158 units in the late 1990s and was successful in reducing the number of adhesion-related incidents. However, the nature of the emergency sander meant it was a single-use device and the train needed to be taken out of service to recharge it after each use.

80 To overcome the limitations of the one-shot sanding system, train operators identified a need for sanders which could be used multiple times during a journey. Automatic sanders, which provided this functionality, were developed and fitted to class 158 units around 2001. After installing automatic sanders, some train operators and owners removed the emergency sanders, although they were retained on TfWRL's class 158 units.

81 As part of the automatic sanding system, each TfWRL class 158 vehicle has a single sand hopper, mounted on the underframe on the non-driver's side ahead of the third wheelset (figure 17). Below the sand hopper are two sand valves, with a sand delivery hose attached to the bottom of each sand valve: one to supply sand to the left wheel, and one to the right wheel.

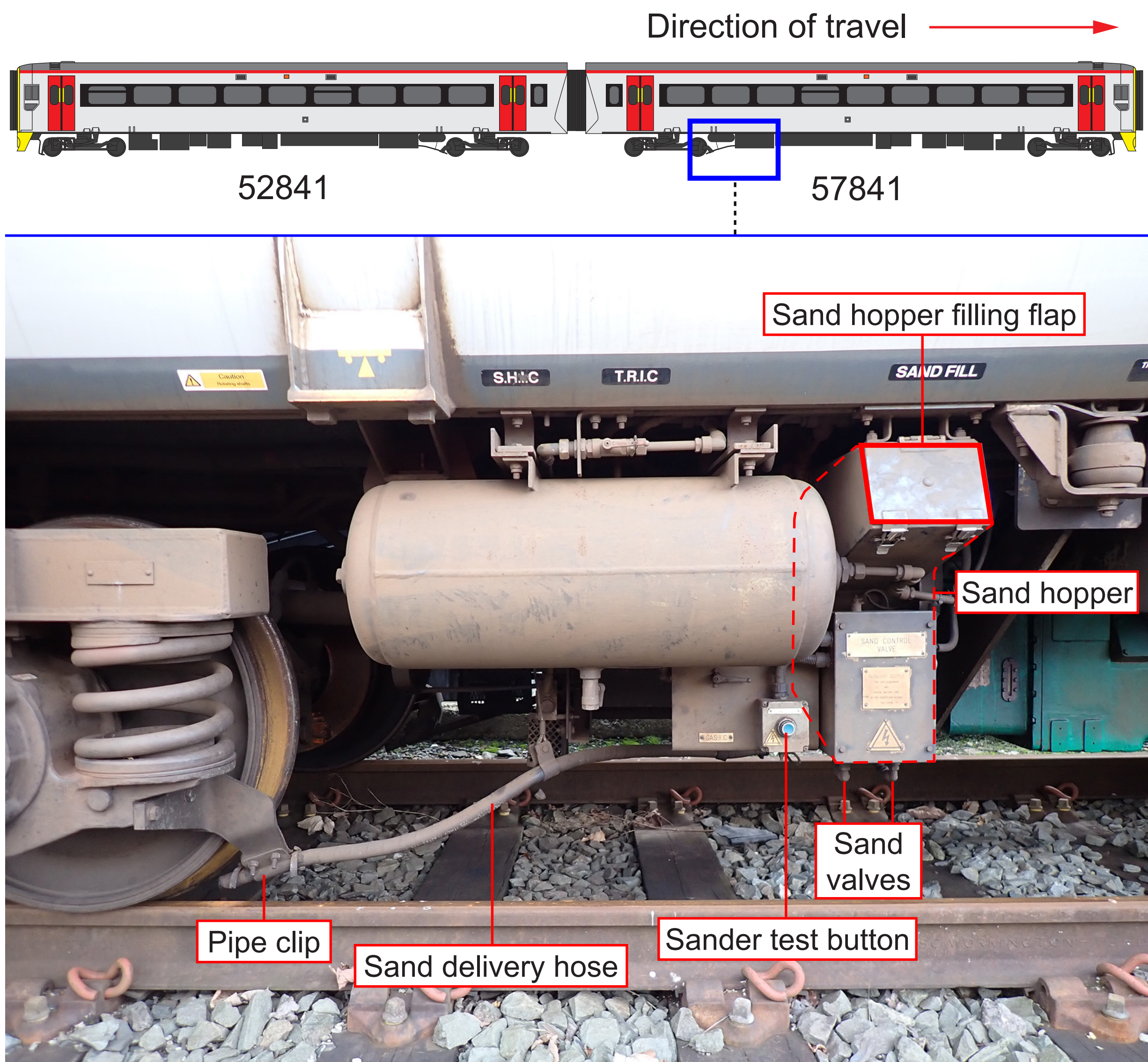

Figure 17: Automatic sanders at third wheelset are available when vehicle 57841 is leading. The same equipment is also installed on vehicle 52841 but will only be available when this vehicle is leading. Main image shows automatic sander equipment in more detail.

82 When sand is needed, compressed air is admitted to the top of the sand valve. This causes sand to flow along the delivery hoses, and it is then ejected from the ends of the hoses, which are directed towards the wheel-rail interface. Further details of the mechanical and pneumatic operation of the automatic sanding system are provided in appendix C.

83 The automatic sanders on TfWRL class 158 units can be operated manually by the driver (using a cab desk push button) when the driver is demanding traction. However, when the unit is braking, the sanders are only operated automatically by the WSP system (see paragraph 88). On TfWRL class 158 units, the automatic sanding system is operational if the train encounters low adhesion when the unit is in brake step two or above. The driver is not provided with any indication in the cab that the automatic sander is delivering sand when demanded.

84 Although these sanding systems are installed on each vehicle, only the sanders on the leading vehicle of each train formation are active. In the case of train 1J25, the only active automatic sanding system at the time of the accident was therefore that fitted to vehicle 57841, directing sand to the third wheelset (from the front) of the train.

Braking systems as fitted to TfWRL class 158 units

85 The braking system fitted to class 158 units decelerates the train by supplying air to brake cylinders mounted on the train's bogies. These brake cylinders apply friction pads to brake discs, mounted on each wheelset. A driver can apply three levels of braking in normal service. Step 1 provides the lowest level of braking, while step 3 (full service braking) provides the maximum braking effort. On level track with good adhesion, a brake step 1 application will typically decelerate the train at approximately 3%g[5] (0.29 m/s^2), while full service braking will decelerate the train at approximately 9%g (0.88 m/s^2).

86 A driver can also make an emergency brake application. The emergency brake applies the same level of retardation as step 3 but uses a different control system so the train can still be braked in the event of a service braking system failure. On the class 158 units operated by TfWRL, the on-board signalling system (paragraph 31) can also apply full service (referred to as a 'Service Brake Intervention' or 'SBI', see paragraph 214) or emergency braking.

87 The TfWRL class 158 units also have auxiliary tread brakes installed on the bogies under each driving cab. These are additional to the disc brakes which provide the primary brake force. Although auxiliary tread brakes provide some additional braking forces, their primary purpose is to clean the wheel treads to enhance train detection. They can also improve wheel-rail adhesion.

Wheel slide protection systems as fitted to TfWRL class 158 units

88 TfWRL class 158 units are fitted with a WSP system. The system fitted is common to that found on the wider class 158 and class 159 fleets and is typical of the equipment found on vehicles of this age. This system monitors the rotational speed of individual wheelsets to detect:

- wheel slip, which can occur during acceleration when a wheelset is rotating faster than the true train speed

[5] Train brake rates are often quoted as '%g'. This is the value of an acceleration (or deceleration) expressed as a percentage of that achieved by a freely falling object, which is taken to be 9.81 m/s^2.

- wheel slide, which can occur during braking, when a wheelset is rotating slower than the true train speed
- wheel lock, which can occur during braking when a wheelset stops rotating altogether while the train is still moving.

89 WSP systems are designed to optimise a train's braking in conditions where there is low adhesion between the wheel and the rail. If the WSP system detects that wheel slide is occurring on one or more wheelsets, it automatically applies a controlled reduction of the brake force on the sliding wheelsets until they begin to 'catch up' with train speed, at which point the requested brake force is reapplied. If wheel slide reoccurs, this process is repeated until the train stops or the brake application is removed. When a significant amount of WSP activity occurs on multiple wheelsets, the cyclical reduction in brake force to control wheel slide on each wheelset can impact on the overall braking performance achieved by the train.

90 Research has shown that some sliding contact between wheel and rail is often beneficial because it can 'condition' the wheel and rail and help to improve the available wheel-rail adhesion for following wheelsets.[6] WSP systems therefore aim to allow some degree of wheel slide, typically permitting individual wheelsets to rotate approximately 15% slower than the corresponding train speed.[7]

91 By having individual wheelset control, the overall effect is far superior to that which could be achieved by a driver trying to control the slide by applying and releasing the brake, as the driver's actions would alter the braking on all wheelsets, whereas the WSP system controls each wheelset separately. WSP systems are also designed to minimise the potential for the wheels to be damaged by excessive wheel slide or, in extreme circumstances, by wheel lock.

92 The WSP system on the class 158 unit can activate the automatic sanding system to increase the available wheel-rail adhesion and hence the available brake force in low adhesion conditions.

93 The WSP equipment fitted to each vehicle comprises a WSP control unit, three speed probes and three dump valves. A speed probe is fitted to each wheelset of the unpowered bogie, with a further speed probe monitoring the rotational speed of the (mechanically connected) wheelsets of the powered bogie. The speed probes sense the rotational speed of the train's wheelsets and provide inputs to the WSP control unit.

94 A dump valve is an electro-magnetically controlled valve, controlling air flow to and from the train's brake cylinders. As with the speed probes, there is a dump valve for each wheelset of the unpowered bogie, and one dump valve controlling both wheelsets of the powered bogie. The WSP control unit uses the dump valves to moderate the brake force applied to each of the wheelsets. The WSP systems on each vehicle of a class 158 unit work independently and there is no link between them.

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[6] British Rail Research Report 'Self Conditioning Tests', RR-SAM-031 dated June 1995, describes wheel-rail conditioning as 'the effect where a slipping wheelset does work at the wheel-rail interface which results in cleaning'.

[7] Seasonal Challenge Steering Group, 'Managing Low Adhesion' seventh edition, dated 2024.

95 When a train is braking and encounters low adhesion, and the demanded brake effort exceeds the available wheel-rail adhesion, the WSP system will intervene to actively control wheel slide and demand sand from the automatic sanding system. This sand, if delivered, will improve the wheel-rail adhesion and hence the braking performance. In the absence of sand, achievable deceleration rates will be highly dependent on the nature of the contamination that is causing the low adhesion.[8]

Identification of the immediate cause

96 **Train 1J25 passed its authorised stopping position and entered a single line occupied by approaching train 1S71.**

97 Signalling data, on-train data, CCTV and witness accounts all support the conclusion that train 1J25 was signalled to stop at block marker MH1078. Despite the driver of train 1J25 applying the brakes with the intention to stop at the block marker, train 1J25 passed through Talerddig loop and onto the occupied single line.

98 Train 1S71 was climbing Talerddig bank at this point with a movement authority that permitted it to continue along the single line to block marker MH1081 (figure 6).

Identification of causal factors

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

a. Train 1J25 was unable to stop at block marker MH1078 and therefore exceeded its movement authority (paragraph 100).

b. Having passed block marker MH1078, train 1J25 entered the occupied single line (paragraph 242).

Each of these factors is now considered in turn.

The approach of train 1J25 to block marker MH1078

100 **Train 1J25 was unable to stop at block marker MH1078 and therefore exceeded its movement authority.**

101 Analysis of on-train data, supported by witness evidence, shows that, given the approach speed and point where the brakes were applied, the train's achieved deceleration was too low to stop it before it passed block marker MH1078 (paragraph 52).

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

a. The available wheel-rail adhesion was unable to support the level of demanded braking without sand being discharged by train 1J25 (paragraph 103).

[8] The achieved deceleration in such a situation is dependent on various aspects, including the design of the WSP system and the wheel-rail adhesion conditions. One of the main factors is the 'creep curve', which describes the relationship between the frictional force available and the amount of slide between the wheel and rail. The creep curve is not a fixed parameter - as a train moves along the track, the creep curves it encounters will constantly be changing.

b. Trainborne systems did not mitigate the prevailing low wheel-rail adhesion because the automatic sander was not working and the driver did not use the emergency sander (paragraph 147).

c. The approach speed of train 1J25 towards the eastern entry to Talerddig loop was such that the subsequently required deceleration could not be sustained with the available wheel-rail adhesion (paragraph 209).

Each of these factors is now considered in turn.

The wheel-rail adhesion on the approach to block marker MH1078

103 The available wheel-rail adhesion was unable to support the level of demanded braking without sand being discharged by train 1J25.

Low wheel-rail adhesion encountered by train 1J25

104 Data from the OTDR on train 1J25 shows that on the approach to Talerddig loop the driver shut off traction power and made two separate brake step 1 applications, followed by periods when the train's brakes were released. The driver then selected brake step 2. This was followed by a full service brake demand which was made by the ETCS system (paragraph 52) and subsequently by the driver. After a few more seconds, an emergency brake application was also made by the ETCS system (paragraph 54).

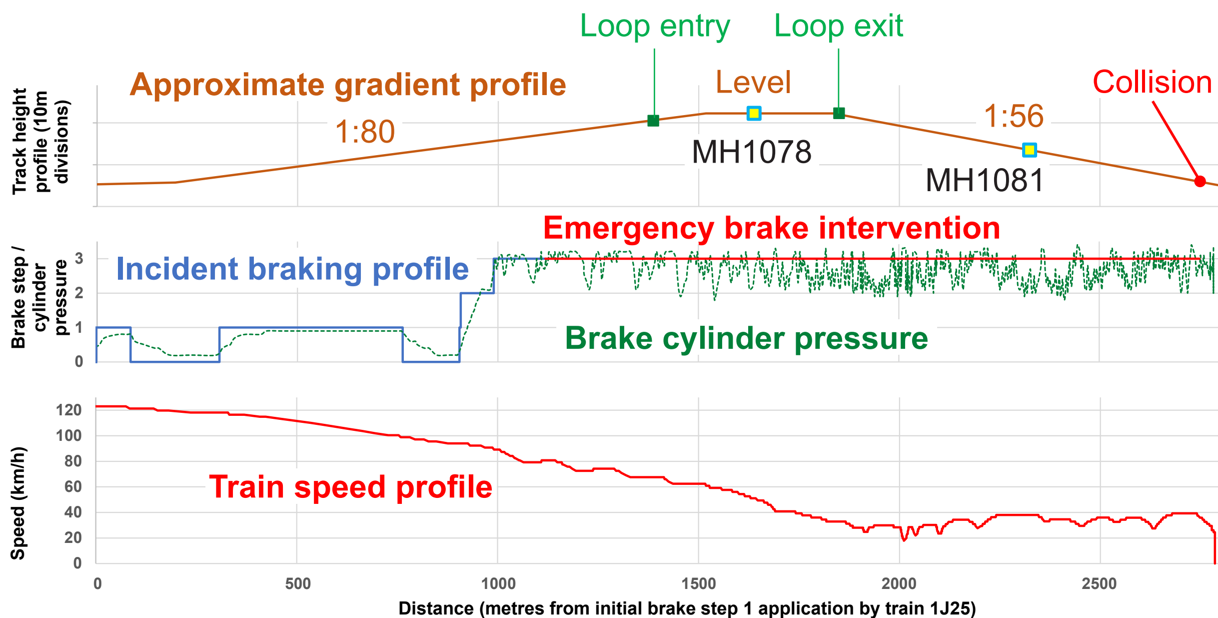

Figure 18: Track gradient on the approach to the accident site, together with OTDR data from vehicle 57841.

105 OTDR data (figure 18) shows that significant pressure fluctuations started to occur as the brake cylinder pressure climbed to the full service brake level (approximately 3 bar). Pressure fluctuations like these normally indicate that the brake demand has exceeded the available wheel-rail adhesion and the train's WSP system is functioning to control wheel slide.

106 It can be observed from OTDR data that, from this point until the collision, the train's speed did not reduce at the rate which would be expected for an emergency brake application. For example, in the Talerddig loop, the train achieved a deceleration of between 3 and 4%g (0.29 and 0.39 m/s^2), while the train braking system was demanding a full service brake application. This would normally be expected to provide a deceleration of approximately 9%g (0.88 m/s^2) in good adhesion conditions.

107 RAIB considered the possibility that there could have been a defect with the braking system. The following evidence has led RAIB to conclude that there were no defects with the braking or WSP system on train 1J25 and they were functioning normally at the time of the accident:

- There were no allegations made by the train driver suggesting anything was wrong with the braking system before approaching Talerddig loop.
- OTDR data from train 1J25 shows that the train decelerated appropriately when the brakes were commanded by the driver during previous station stops. OTDR data also shows that during the incident the brake cylinder pressure responded appropriately to brake demands.
- RAIB witnessed post-incident testing which confirmed that all brake equipment was present. There were also no obvious contamination nor signs of excessive heat on brake discs or pads. The testing also confirmed that, when the brakes were commanded on the brake controller, appropriate pressures were created at the test points for the brake cylinders, and this pressure also registered on the cab gauge. All measured brake air pressures were compliant with those stated in the TfWRL maintenance plan for class 158 units.
- Train 1J25 suffered significant damage during the accident, including damage to its compressed air lines and fittings. After temporary repairs to resolve damage from the accident, train 1J25 was moved around the depot under its own power with no relevant issues identified with the braking system.
- Testing of critical components from the brake and WSP system did not identify any faults (see paragraph 152).

Weather and adhesion forecasts

108 On 18 October (3 days before the accident), the Met Office (the UK's national weather service) reported that named storm 'Ashley' was forecast to bring strong winds and heavy rain to the UK on 20 and 21 October 2024. The summary report for Storm Ashley was issued by the Met Office on 24 October (3 days after the accident). It stated that '*Storm Ashley, the first named storm of the 2024/25 season, brought wet and windy weather to the UK in late October with the strongest winds across north-western areas. This was a powerful, although not exceptional, Atlantic autumn storm*'.

109 Network Rail has a contract with a national weather forecast provider, MetDesk Ltd, to provide regional weather forecasts and daily adhesion forecasts. In the 5-day regional weather forecast report, weather conditions are classified using a scale from green (normal), yellow (aware), orange (adverse) and red (extreme). This scale is applied separately to flooding, rain, wind and snow.

110 The forecast for central Wales (which includes the Cambrian lines and the Talerddig area) for 21 October 2024 showed a yellow (aware) warning for heavy rain and green (normal) for all other weather categories (figure 19).

Summary Hazards - Central (Wales)																				
Day (0600 to 0600)	Wind		Heavy Rain Accum.		Convective Rainfall Intensity		Snow		Frost		Min Temp Morn (06-11)	Max Temp (06-18)	Min Temp (18-06)	Temp Range		Ice Day		Lightning Risk	
	Hazard	Conf.	Hazard	Conf.	Hazard	Conf.	Hazard	Conf.	Hazard	Conf.				Hazard	Conf.	Hazard	Conf.	Hazard	Conf.
Mon		High	Aware	Low		Low		High		High	9.0	15.5	7.0		High		High		Low
Tue		High		Low		Low		High		High	8.5	16.5	8.0		High		High		Low
Wed		High		High		High		High		High	8.0	16.5	7.5		High		High		High
Thu	Aware	Low	Aware	Medium		Low		High		High	7.5	17.5	6.5		High		High		Low
Fri		Low	Aware	Low		Low		High		High	6.5	15.0	2.5		High		High		Low

Figure 19: Extract from the MetDesk 5-day weather forecast for central Wales, with circled area showing there were no warnings for wind, but there was a yellow 'aware' warning for heavy rain on Monday 21 October 2024 (courtesy of MetDesk).

111 MetDesk's adhesion forecast reports are usually issued between 02:00 and 03:00 for the day ahead. They provide an adhesion forecast at hourly intervals for the upcoming 2 days, with 4-hourly interval forecasts for days 3 to 5. The adhesion forecasts are based on rainfall, leaf fall, dew point and rail temperatures.

112 The adhesion forecast uses an adhesion risk score which runs between 0 (good) and 10 (very poor). These scores are then categorised into five colour-coded levels, from 'good' adhesion (green) progressing through 'poor' (red) where there is a high risk of leaf fall and disruption to the network if the railhead is not treated. 'Very poor' adhesion' (black) is the most severe category, with very high contamination likely due to leaf fall and damp conditions with a very high risk of disruption to the rail network (figure 20). The adhesion forecasts are usually updated at around 14:00 each day.

Adhesion Index	Description
0 to 2	**Good adhesion conditions expected** Leaf contamination unlikely except in very prone locations. Rails generally dry or briefly damp.
3	**Wet railhead expected** Rails damp or wet, generally devoid of leaf contamination away from prone spots, but sufficient to reduce adhesion between the wheel and rail, potentially leading to wheel slippage.
4 to 5	**Moderate adhesion conditions** Moderate leaf fall risk with dry conditions. Slight contamination with damp rail. Some disruption to the network could be expected, especially in cuttings or densely vegetated areas.
6 to 8	**Poor adhesion conditions** High leaf fall risk with dry conditions. Moderate leaf fall contamination with damp rail conditions. Disruption to the network likely if treatment not completed.
9 to 10	**Very poor adhesion to extreme leaf fall conditions** Very high contamination of the railhead due to leaf fall. High to very high contamination of the railhead due to leaf fall and damp rail conditions. Very high risk of disruption to the network

Figure 20: Replication of Network Rail's Adhesion Index forecast table (courtesy of Network Rail).

113 A MetDesk adhesion forecast (figure 21) was issued on 21 October at 02:31 and summarised that '*adhesion will be mostly moderate, tending to improve during the day under drier, sunnier conditions, though some pockets of poor adhesion are possible locally in Wales*'. The forecast adhesion index for the Talerddig area was 7 (poor adhesion). When the forecast was updated later in the day (at 14:10, figure 22), the adhesion index had reduced slightly to 6 (poor adhesion).

Central	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00	01	02	03	04	05
Adhesion average	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6	6	5	6	6	6	6	6	6
Abergavenny	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6	6	6
Church Stretton Station	5	5	5	5	5	5	5	6	6	5	5	5	5	5	6	6	6	6	6	6	6	6	6	6
Talerddig to Cemmes Road LC	7	7	7	7	7	6	5	5	5	5	5	5	5	7	7	7	7	7	7	7	7	7	7	6
Llandre Vicarage LC to Aberystwyth No.1 GF	7	7	7	7	7	7	6	6	6	6	6	5	5	5	6	6	6	6	6	6	6	6	6	6
Dew Point average	9	9	9	9	9	9	9	9	8	8	9	9	9	8	8	8	8	8	9	9	9	9	9	9

Figure 21: Extract from the MetDesk 24-hour adhesion forecast for central Wales area, which was issued at 02:31 on the day of the accident (courtesy of MetDesk). The adhesion index score of 7 for the Talerddig area at 19:00 is circled.

Central	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00	01	02	03	04	05
Adhesion average	5	5	5	5	5	5	5	4	4	5	5	5	5	5	5	5	5	5	6	6	6	6	6	6
Abergavenny	5	5	5	5	5	5	5	4	4	5	5	5	5	5	7	7	7	7	7	7	7	7	6	6
Church Stretton Station	5	5	5	5	5	5	5	6	6	7	6	5	5	5	5	5	5	5	6	6	6	6	6	6
Talerddig to Cemmes Road LC	7	7	7	7	7	7	7	6	6	7	6	7	7	6	5	5	5	5	7	7	7	7	6	7
Llandre Vicarage LC to Aberystwyth No.1 GF	7	7	7	7	7	7	7	6	6	7	7	7	6	7	7	7	7	6	6	6	6	6	6	6
Dew Point average	9	9	9	9	9	9	9	9	8	8	8	9	8	8	8	8	8	8	8	9	9	9	9	9

Figure 22: Extract from the MetDesk 24-hour adhesion forecast for central Wales area, which was issued at 14:10 on the day of the accident (courtesy of MetDesk). The adhesion index score of 6 for the Talerddig area at 19:00 is circled.

Actual weather conditions

114 In order to understand what the likely weather conditions were in the Talerddig area in the hours before the accident, RAIB commissioned the Met Office to undertake a detailed weather analysis. This used observations from weather stations and high-resolution weather radar imagery.

115 The Met Office report summarised Storm Ashley as '*not an exceptional Atlantic storm from a weather perspective, it was a notable storm from a leaf fall perspective across northern and central areas of the UK. The strong winds were a key factor in removing large quantities of leaves from the* [tree] *canopy* [on] *the day preceding the collision'.*

116 The Met Office analysis considered if the rails at Talerddig were likely to have been damp at the time of the accident. This analysis used high-resolution weather radar imagery, supplemented by observations from weather stations.

117 Analysis of rainfall radar imagery shows that there was persistent light rainfall on 21 October from the early hours until approximately 08:00. The weather then turned dry, until a shower brought rainfall to the Talerddig area around 19:00 and then over the collision site at 19:05 and 19:10 (figure 23). The rainfall was light with rain rates between 0.01 and 1 mm/h. The shower is shown to reduce in extent and intensity as it passes over the line and is likely to have introduced low levels of moisture onto the railhead.

118 The rainfall radar imagery indicates that it was not raining in the vicinity of train 1J25 at the time it started braking for Talerddig loop at 19:22; this is supported by the available witness evidence. Sunset occurred at approximately 18:05, and so it was dark by this time, with cooling temperatures reducing the rate of drying by evaporation. It is, therefore, likely that the railhead remained damp following the rainfall.

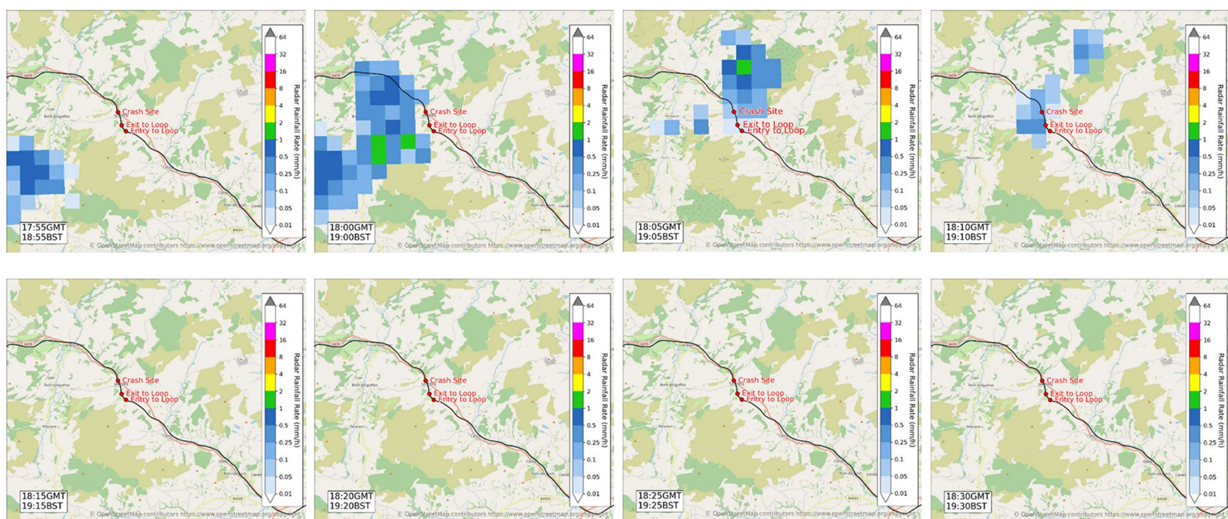

Figure 23: Instantaneous rain rates from Met Office radar on 21 October 2024 along the Cambrian lines, at 5-minute intervals from 18:55 to 19:10 (top row) and 19:15 to 19:30 (bottom row). Times in BST (courtesy of Met Office).

119 The Met Office study also considered the wider geographical area and time period for the entire journey of train 1J25 from Shrewsbury to Talerddig. This concluded that train 1J25 did not encounter any showers on the journey towards Talerddig. This further confirmed that the shower which occurred at Talerddig had cleared by the time train 1J25 started to brake on the approach to Talerddig loop at 19:22.

120 The driver of train 1J25 did not see any rain falling on the approach to Talerddig loop, and, given that it was dark, was probably not aware that a shower had recently passed over Talerddig, leaving the rails damp.

RAIB observations of railhead contamination, samples and laboratory analysis

121 RAIB undertook an inspection of the rails at Talerddig at around 02:00 on the night of the accident. Some rain fell during this inspection. Visible contamination was observed on the railhead, which was assessed by RAIB as being relatively light and intermittent (figure 24).

Figure 24: Example of visible contamination observed on the railhead between the collision location and Talerddig loop at around 00:45 hours on 22/10/2024.

122 A more detailed inspection of the rails was carried out during daylight (figure 25). This revealed light contamination in several areas, including the descending gradient leading to the collision location (see paragraph 248).

Figure 25: Example of visible contamination observed on the railhead at around 11:25 hours the morning after the accident, on the approach to the loop at 1400 metres (left) & 1500 metres (right) on approach to the point of collision.

123 RAIB also collected railhead contamination samples on the day after the accident, including railhead scrapings (figure 26).

124 RAIB commissioned the University of Sheffield to undertake laboratory analysis of the collected railhead samples. The analysis sought to identify what compounds were present in the samples, and to determine if any typical railhead cleaning products, adhesion modifiers (see paragraph 140) or lubricants were present in the samples. The analysis found that the railhead samples contained iron (most likely to be corrosion from the steel rails) and leaf material. The analysis also found that an organic compound which is used as an adhesion modifier used by Network Rail may have been present.

Examination of the wheels on train 1J25

125 There was no visible contamination on the wheels of the train when these were inspected. For this reason, RAIB did not collect any samples from the train's wheels.

Figure 26: Example of sample collection (scraping) on the day after the accident, taken at a location 550 metres on approach to the point of collision.

126 No evidence was found of tread damage to the train's wheels, including the 'flats' which are normally associated with wheels locking (paragraph 88). RAIB concluded, therefore, that the wheels on train 1J25 continued to rotate throughout the accident, under the control of the train's braking and WSP systems.

Friction measurements conducted on site by RAIB

127 RAIB took sample measurements using a digital tribometer, which can estimate the adhesion which is available over the measurement distance. The measurements were taken at around 03:00 on 22 October, approximately 8 hours after the accident. It had rained during the intervening period and these measurements may not be representative of the conditions at the time of the accident. Three spot measurements were taken at 500, 1000 and 1500 metres on approach to the point of collision and ranged between peak $\mu = 0.03$ and peak $\mu = 0.09$, indicating 'exceptionally low' and 'low' adhesion when compared to the adhesion categories in table 1.

WSPER testing and simulation to estimate the wheel-rail adhesion

128 Wheel-rail adhesion is a highly variable parameter over both time and location. As the spot measurements were limited in number and were taken around 8 hours after the accident, RAIB commissioned simulations of the Talerddig accident on the WSP Evaluation Rig (WSPER) system. The WSPER system is a real time 'hardware in the loop' simulation facility which is extensively used by the rail industry for the independent evaluation of rail vehicle WSP systems. The simulations commissioned by RAIB were used to estimate the underlying adhesion conditions present during the Talerddig accident. This testing also allowed RAIB to simulate other scenarios in order to understand the potential effect of changes (for example, the effect of sanding).

129 The testing used the WSP equipment (paragraph 88) recovered from train 1J25 in these simulations. Models were constructed in the simulator for the train involved, the infrastructure (including track gradients) and train operation (entry speed and brake demands).

130 The WSPER system has a library of adhesion profiles which are based upon actual track measurements that were originally captured by the British Rail Research tribometer train and represent a wide range of operating conditions.

131 The starting point for the WSPER simulations (0 metres) is the location where the driver first selected step 1 braking on the approach to Talerddig loop (paragraph 52). On this baseline,[9] block marker MH1078 is located at a distance of 1638 metres, the descending gradient starts at 1890 metres, and the collision occurs at 2750 metres. This baseline is used for all further graphs in this report.

132 The data from the OTDR on train 1J25 provided an actual speed profile for the incident. A series of WSPER simulations were undertaken with different adhesion profiles, iterating until the speed profile from the simulation was comparable to the actual OTDR speed profile from the incident. After this iterative process, the best match was found with an adhesion profile with a peak[10] μ value of 0.06 on the approach to block marker MH1078. This is classed as 'low adhesion' (paragraph 74, table 1 and figure 27). This level of wheel-rail adhesion was not exceptional for the area around Talerddig during October. Beyond block marker MH1078, the WSPER simulations estimated that the adhesion would reduce to peak μ = 0.05, before reducing to peak μ = 0.035 (exceptionally low adhesion) on the descending gradient beyond Talerddig passing loop.

133 The closest WSPER approximation to the incident was achieved with a combination of three adhesion profiles which provided a similar speed profile at specific locations. However, the train would have encountered variable adhesion conditions throughout the site, with some sections of lower adhesion and some sections of higher adhesion, all with different characteristics. RAIB considers that this 'average adhesion' approach derived during WSPER testing is adequately detailed to understand the accident for the purposes of this investigation.

The management of low wheel-rail adhesion in the Talerddig area by Network Rail

134 Decisions on the regime that was used to manage the railhead conditions during the autumn season were set out in a joint seasons' plan developed by staff from Network Rail and TfWRL (appendix E).

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[9] OTDR data was used to create the WSPER baseline distance because it contained more relevant data channels at a greater resolution than the JRU data. However, OTDR distance data is based on wheel speed and is therefore more susceptible to small distance errors during wheel slide. The JRU data is less susceptible to these errors because it supplements wheel speed data with Doppler radar data. The WSPER baseline distances are therefore slightly different to the distances used elsewhere in this report.

[10] Wheel-rail adhesion profiles (also known as creep curves, see paragraph 93) are typically referred to by their peak (highest) adhesion value on the profile. These adhesion profiles describe the relationship between the frictional force available and the amount of slide between the wheel and rail. At higher levels of slide, the frictional force available for braking will be lower than the peak value.

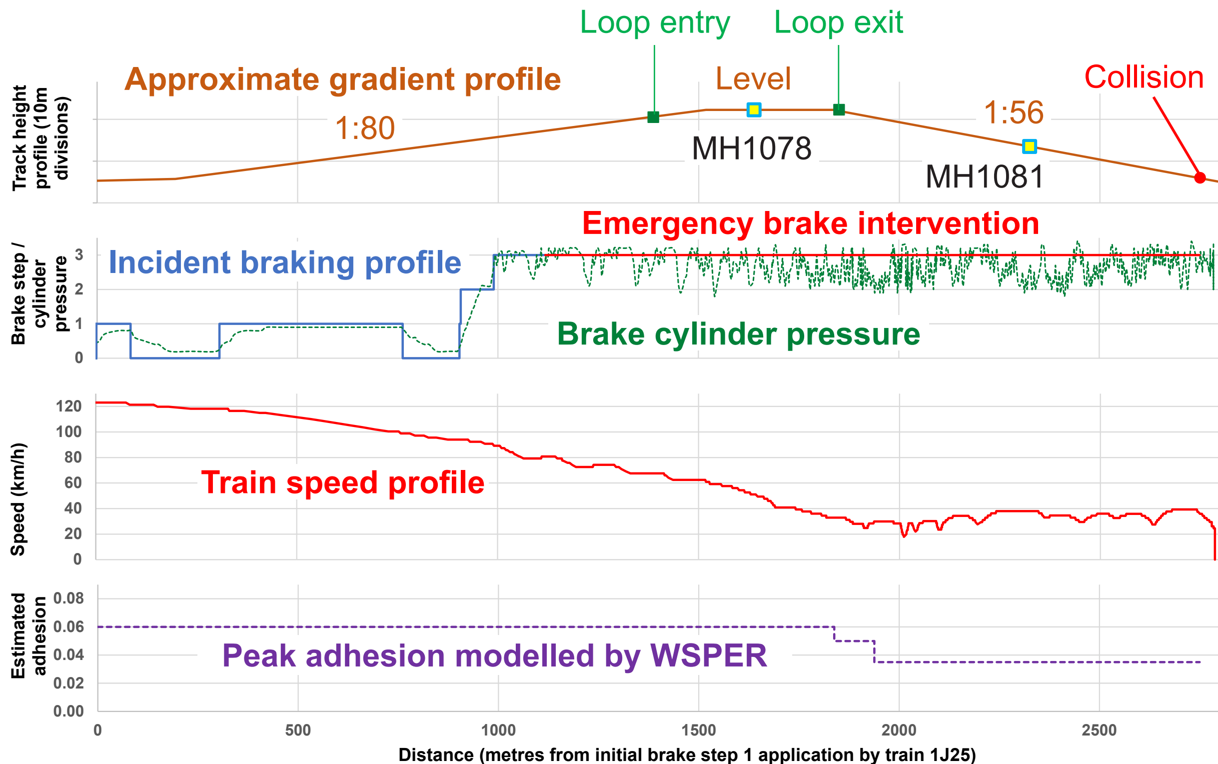

Figure 27: Track gradient on the approach to the accident site, together with OTDR data from vehicle 57841 and the peak adhesion modelled by WSPER.

135 During the leaf fall season, which Network Rail defines as running from 1 October to 13 December each year, the track at Talerddig was scheduled to be treated by an RHTT (paragraph 44) 6 days a week (Sundays excluded) regardless of actual track conditions or the anticipated weather. The RHTT assigned to the route through Talerddig comprises an ETCS-equipped locomotive and a rake of wagons configured to clean the railhead with very high-pressure water jets. These jets are intended to blast off any contaminants and seek to restore the railhead condition. Network Rail installed GPS-enabled equipment to monitor RHTT progress and show where it had treated sections of track. The train covers a substantial route mileage, including the Cambrian lines.

136 The very high pressure at which the RHTT delivers water was chosen to ensure effective railhead cleaning at relatively high train speeds. This reduces the disruption that RHTT movement causes to passenger services. A consequence of the high pressure is that an RHTT can permanently damage the rail if the jet is allowed to dwell. As a result, Network Rail requires that RHTTs do not treat at speeds below 8 km/h. This is achieved by the RHTT operator switching off the water jets when travelling at low speed.

137 Within Network Rail's Wales and Borders route, RHTTs are also not permitted to water jet through points to prevent damage and removal of lubricant. Therefore, RHTT operators are required to switch off the water jets when traversing the entry and exit points of Talerddig loop.

138 The RHTT assigned to the route through Talerddig treats the line from Shrewsbury to Machynlleth, where it reverses direction. This means that the track at Talerddig is treated twice each day, as the RHTT is active in both directions. Because Talerddig is quite near to Machynlleth, both treatments undertaken in any single day typically take place in relatively quick succession.

139 The Cambrian RHTT passed through Talerddig Down Loop at 21:07 during the night of 20 October 2024. It then changed direction at Machynlleth, before passing through the Up Loop between 22:55 and 23:17, stopping to allow another train to pass. The Up Loop at Talerddig was measured by RAIB to be 459 metres between the toes of the points at each end. As a result of the train being stationary in the Up Loop the operator switched off the water jets. GPS data shows that a section of around 55 metres of the Up Loop was not jetted as a result. To comply with the requirement to avoid jetting through points, the jets were also turned off for around 74 metres at the western end of the loop and for about 82 metres at the eastern end. This meant that approximately 211 metres of the path later taken by train 1J25 were not treated (46% of the loop). However, RAIB found no evidence to indicate that these sections of non-jetted track had any effect on the accident.

140 The RHTT used on the Cambrian lines is fitted with equipment that can deliver an adhesion modifying gel to the railhead after the water jets have cleaned it. This gel contains sand intended to enhance adhesion. Network Rail's, seasonal delivery staff (see paragraph 384) decided that the adhesion modifying gel would not be used along the Cambrian lines. The staff who made this decision did so on the basis that the benefits of the gel were unclear and did not outweigh concerns they had about how it may possibly cause fallen leaves to adhere to the railhead when they might otherwise not do. This is discussed further in paragraph 383.

141 During the leaf fall season, Network Rail engages a contractor to supply Autumn Response Teams (ARTs, appendix E). ARTs proactively inspect areas where low adhesion is a concern. One such area was Talerddig. A visual inspection undertaken on part of Talerddig loop at 17:15 on 20 October did not reveal any concerns regarding railhead condition.

142 No drivers had reported abnormally low adhesion in the Talerddig area during the course of 21 October. Train drivers are expected to report to the signaller any abnormal conditions using a TIGER (Track Is Good, Expected, Reportable) mnemonic, reporting only rail adhesion which is worse than would be expected for the location and environmental conditions. Reports of this type had been raised on the Cambrian lines on 19 and 20 October, but neither of these covered the Talerddig area.

143 Although rainfall (paragraph 117) occurred after the passage of the trains preceding train 1J25 through the area, the conditions forecast immediately before the accident did not warrant any specific actions on the part of either Network Rail or TfWRL to address them.

Summary of issues associated with low wheel-rail adhesion

144 In summary, significant winds in the days preceding the accident likely contributed to leaf fall, and the rails were wet before the accident. Both factors are conducive to producing low wheel-rail adhesion. Following the accident, RAIB found intermittent visible patches of relatively light contamination on the railhead, and measurements identified that low wheel-rail adhesion existed. This was further confirmed by the results of testing and simulation work. These showed that conditions of low wheel-rail adhesion existed on the approach to block marker MH1078, and that adhesion was exceptionally low between the block marker and the collision location (an existing area known to be at high risk of low adhesion). This is not atypical of a rural area in Autumn.

145 Analysis of railhead samples found evidence of iron and leaf material, and a possible trace of adhesion modifier, but no other sources of contamination. Network Rail's approach to low adhesion meant the rails in the Talerddig area were cleaned the night before the accident, and its overall management of this issue was compliant with its internal requirements and the joint plan prepared with TfWRL.

146 Given that the braking system of train 1J25 was found to be functioning correctly (paragraph 107), RAIB concluded that the available wheel-rail adhesion was unable to support the level of braking demanded without sand being discharged (paragraph 75) by the train. With that finding, and the train's approach speed to the loop at Talerddig (see paragraph 209), the WSPER testing concluded that, had wheel-rail adhesion been medium or high (paragraph 74, table 1), the train would have stopped at the block marker as intended, without the need for sand (see paragraph 148).

Trainborne systems on train 1J25

147 **Trainborne systems did not mitigate the prevailing low wheel-rail adhesion because the automatic sander was not working and the driver did not use the emergency sander.**

148 Train 1J25 had three systems to mitigate effects of low wheel-rail adhesion. These are:

- The WSP system, which is designed to optimise a train's braking in low adhesion, while minimising the risk of damage which could occur if wheels rotate too slowly or stop rotating altogether (paragraph 88). The WSP system worked normally during the accident and is discussed in more detail in paragraph 149.
- The automatic sanding system, which is designed to be operated by the WSP system to deliver sand. This system did not deliver sand during the accident, probably due to the presence of electrical faults; these are discussed in paragraph 154.
- The emergency one-shot sanding system is fitted on the leading wheelset and is independent of the automatic sanding system. The emergency sanding system is designed to be manually activated by a driver pressing a plunger in the driving cab. The emergency sanding system was not used during the accident and is further discussed in paragraph 193.

Examination of the WSP system on unit 158841 (train 1J25)

149 The OTDR fitted to train 1J25 does not directly monitor WSP activity. However, analysis of other data channels (paragraph 107) suggests that the WSP system was working normally to control the train's braking in low adhesion. There is no evidence that any wheelset stopped rotating (became locked) during the accident at Talerddig. RAIB did not find any wheel flats during post-accident visual inspection (paragraph 126), and after the accident the train was moved from Talerddig to Machynlleth depot at low speed, and there was no evidence (sounds) of any wheel flats during this movement.

150 After the accident, RAIB recovered critical components of the braking system, including the WSP control units, the brake relay valves and the dump valves. These items were all bench tested by the manufacturer. Although some minor air leaks were identified, these would not have contributed to the accident, and no further faults were found (paragraph 107).

151 The WSP system was also subject to further testing, including simulations (paragraph 128). Again, no faults were found and the testing report concluded that the '*results demonstrate a WSP performance typical of systems of that generation with nothing seen to suggest any issues that might have contributed to the incident*'.

152 When the WSP system is actively controlling wheel slide, it produces an SD (slide detected) output which, via an electrical circuit (see paragraph 159), controls the automatic sanding system. During the WSPER testing, the SD output from the WSP control unit of vehicle 57841 was monitored and used to control the simulated effect of sand. The SD output worked as expected during testing.

153 This evidence has led RAIB to conclude that the WSP system was functioning normally and its performance was typical of systems of that generation of equipment design.

Examination of the automatic sanders on unit 158841 (train 1J25)

154 Following the accident, RAIB inspected and tested the automatic sanding system on vehicle 57841. Five faults were identified during this activity:

- Both sand delivery hoses were found to be blocked (see paragraph 156); testing found the blockage comprised mainly leaf material. RAIB has concluded that the hose blockages would probably have been ejected if the sanding system had functioned normally (see paragraph 172).
- The sander isolation switch (SIS), which provides electrical power to the automatic sanding system, was not allowing current to pass. If present at the time of the accident, this fault would have prevented the automatic sander from operating (see paragraph 162).
- The low-speed relay (LSR4[11]) is a device which inhibits automatic sanding below a threshold speed (see paragraph 160). This relay was found to be defective when tested. If present at the time of the accident, this fault would also have prevented the automatic sander from operating (see paragraph 167).
- The orifice plates (metal discs with small holes), which are part of the sander pneumatic system, were found to be installed incorrectly. This fault could lead to a reduced sand delivery rate from an otherwise functional automatic sander. Analysis by RAIB determined that this defect would have had a negligible effect on the accident at Talerddig (see paragraph 399).
- One of the sand delivery hoses was partially constricted by a deformed hose clamp. This would have reduced the sand delivery rate. Analysis by RAIB determined that this defect would again have had a negligible effect on the accident at Talerddig (see paragraph 400), had the sanders been operating.

155 No defects were found on vehicle 52841 except for a blocked sand delivery hose on the non-driver's side.

[11] There are a number of other low-speed relays on a class 158 vehicle, fulfilling functions not relevant to this accident. Only LSR4 is relevant to this investigation.

Blocked sand delivery hoses

156 The blocked sand delivery hoses on train 1J25 were identified shortly after the accident and while the trains were still at Talerddig. On vehicle 57841, which was leading and therefore had the only active sanding system, both sand delivery hoses were blocked (figure 28). On vehicle 52841, which was trailing, only the non-driver's side sand hose was blocked, although there was some material around the rim of the hose end on the other side (figure 29).

157 After the accident, RAIB removed the blocked sand hoses from vehicle 57841 for analysis and testing. The non-driver's side hose had a dome-shaped plug of material visible on the end of the hose, which extended approximately 30 mm deep inside the hose. The driver's side hose had a blockage that was approximately 25 mm in depth. Both blockages appeared to be formed of organic material, and neither hose had any build-up of sand behind the blockage. Visual examination of the inside of the two hoses taken from 57841 showed the hoses to be otherwise clean, indicating that the blockage material had not come down the hose from the sand hopper. Appendix D provides further information on the materials found within the blocked hoses, and the possible mechanism which led to the hoses on both vehicles becoming obstructed.

Figure 28: The blocked sand delivery hoses, as found on leading vehicle 57841; left: driver side hose; right: non-driver's side hose.

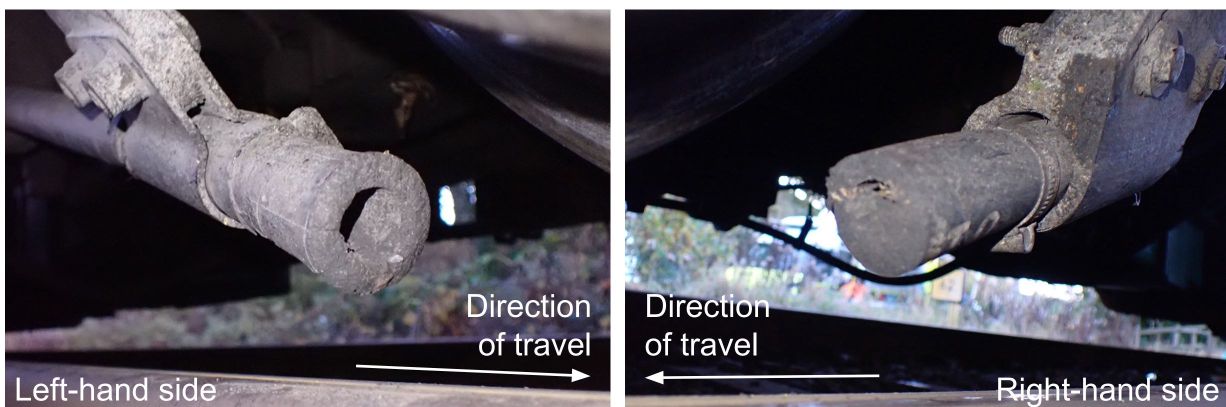

Figure 29: The sand delivery hoses, as found on trailing vehicle 52841; left: driver side hose; right: non-driver's side hose.

158 The discovery of the blocked sander hoses led RAIB to carry out detailed examination and testing of the sanding systems fitted to both vehicles 57841 and 52841. This examination is described in the subsequent paragraphs.

Automatic sander electrical control circuit

159 The air supply used to deploy sand is controlled by an electro-magnetic valve which is located near the sand hopper on each vehicle. The closure of the SD electrical contact (paragraph 152) provides the initial trigger for sand to be demanded. However, additional electro-mechanical relays and switches are used to inhibit this demand when it is not desirable to deploy sand because of a vehicle's direction, speed or brake step, or if it is coupled behind another unit (paragraph 84).

160 For the sand valve to be energised by the WSP control unit, the following conditions must be met:

- The SIS must be closed.
- A contact of LSR4 must be closed. This contact is closed by energising the coil of LSR4. This coil is fed by the WSP control unit closing an internal electrical contact known as the low-speed contact. The low-speed contact controls the supply to the coil of the LSR4 relay by closing when the vehicle accelerates above 10 km/h and opening when the speed falls below 5 km/h. This stops sand from being discharged at slow speeds.
- A contact of the 'sand wheel slide relay' (SWR) must be closed. This contact is closed by energising the coil of this relay. This coil is fed by the WSP control unit closing the SD electrical contact (paragraph 152).
- A series of selection relays verify the direction of travel of the vehicle, that the vehicle is leading and that the vehicle is in brake step 2 or above (paragraph 84).

When these conditions are met, the sand valve is energised, and air is admitted, deploying sand.

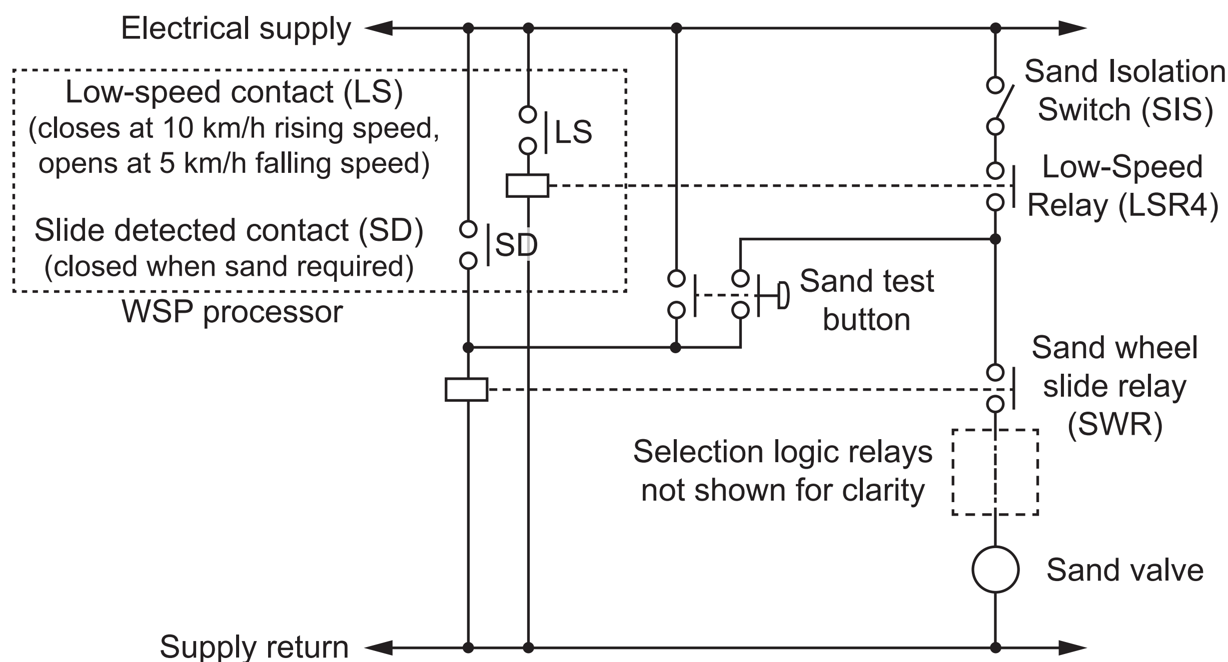

Figure 30: Simplified schematic of the electrical sanding control circuitry.

161 In addition to the sand demand originating from the WSP control unit, a manual sander test button is provided on the vehicle underframe. This external test button is used by staff to activate the sand valve. The delivery of sand from the sand delivery hoses can then be observed. The purpose of this test is to check that sand is ejected from the sand delivery hoses before the unit enters service (paragraph 42). The sand test button energises the sand valve via a route which bypasses the relevant SIS and LSR4 contacts (figure 30).

Sander isolation switch (SIS)

162 The sanding equipment fitted to class 158 units is provided with a switch in each driving cab to allow the driver to isolate the system if required (appendix C). Each SIS is located on the rear wall behind the driver. The SIS works by electrically disconnecting the power supply to the sanding equipment on the vehicle to which it is fitted and does not isolate the sanding system on the adjoining vehicle.

163 During post-accident testing undertaken on 8 January 2025, RAIB found that the SIS in unit 57841 had failed to a high resistance state when in the 'on' position. This had the effect of preventing electrical current flowing to the sanding system, even with the switch in the on position.

164 The SIS is provided with a seal to indicate when it has been used and to prevent erroneous operation. This seal was unbroken and a build-up of dirt around the seal indicates the SIS had almost certainly not been moved from the on position in the recent past (figure 31).

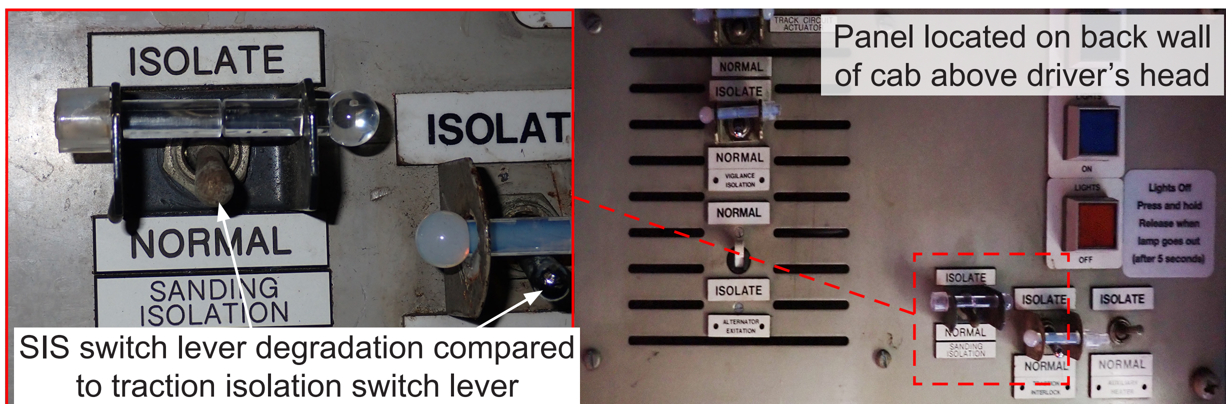

Figure 31: The sand isolation switch located at the rear of the cab of unit 57841 showing the condition of the switch and seal.

165 To continue testing, the SIS was electrically bypassed, and the switch removed for further testing by RAIB. This testing confirmed the high resistance state of the switch. Normal electrical function of the switch was restored following a small number of operations of the switch lever. The two usual explanations for a switch developing a high resistance are oxidisation of the contact surface or the introduction of a foreign body which separates the internal switch contacts. A foreign body would need to be drawn between the contacts, which are held closed by spring pressure, as the switch is operated from the off to the on position. In this instance, the SIS had not been operated for a long period of time and had successfully completed many depot examinations which would have revealed the fault. Therefore, RAIB has concluded that the most likely explanation for the fault is that the SIS contacts had become oxidised.

166 The contacts of a closing switch are designed to move against each other in such a way as to scour the two mating contact surfaces as they come together. However, when not operated for a period, switches can build up a layer of oxidisation on closed contacts causing increased resistance to electrical current. This will continue to develop unless broken down either by sufficient electrical current passing through the switch to erode the oxidisation, or by the operation of the switch itself. Although RAIB did not disassemble the SIS, the restoration of the switch function when the switch was operated during the testing is also indicative of oxidisation build-up.

Low-speed relay (LSR4)

167 A build-up of discharged sand can, in some circumstances, prevent a train from being detected by railway signalling systems (appendix C). To address this issue, class 158 units prevent sand from being deployed at low speed by use of an electromechanical relay contact within the electrical supply downstream of the SIS in the sander activation circuit (figure 30). This is the LSR4 relay (paragraph 160).

168 The sanding system on unit 57841 failed to operate correctly during the post-accident testing conducted by RAIB on 8 January 2025, even once the SIS was bypassed. RAIB found that the LSR4 relay was not closing its contacts when electrical current was applied to the coil, as it was designed to do.

169 The LSR4 relay was located under the driver's desk and close to the front of the unit damaged by the impact. Despite this, the relay was correctly seated in its base receptacle and a spring clip, intended to prevent the relay from being dislodged, was engaged. This type of relay is provided with an override push button which acts upon the internal mechanism to allow the manual closing of the (normally open) contacts for testing purposes (figure 32).

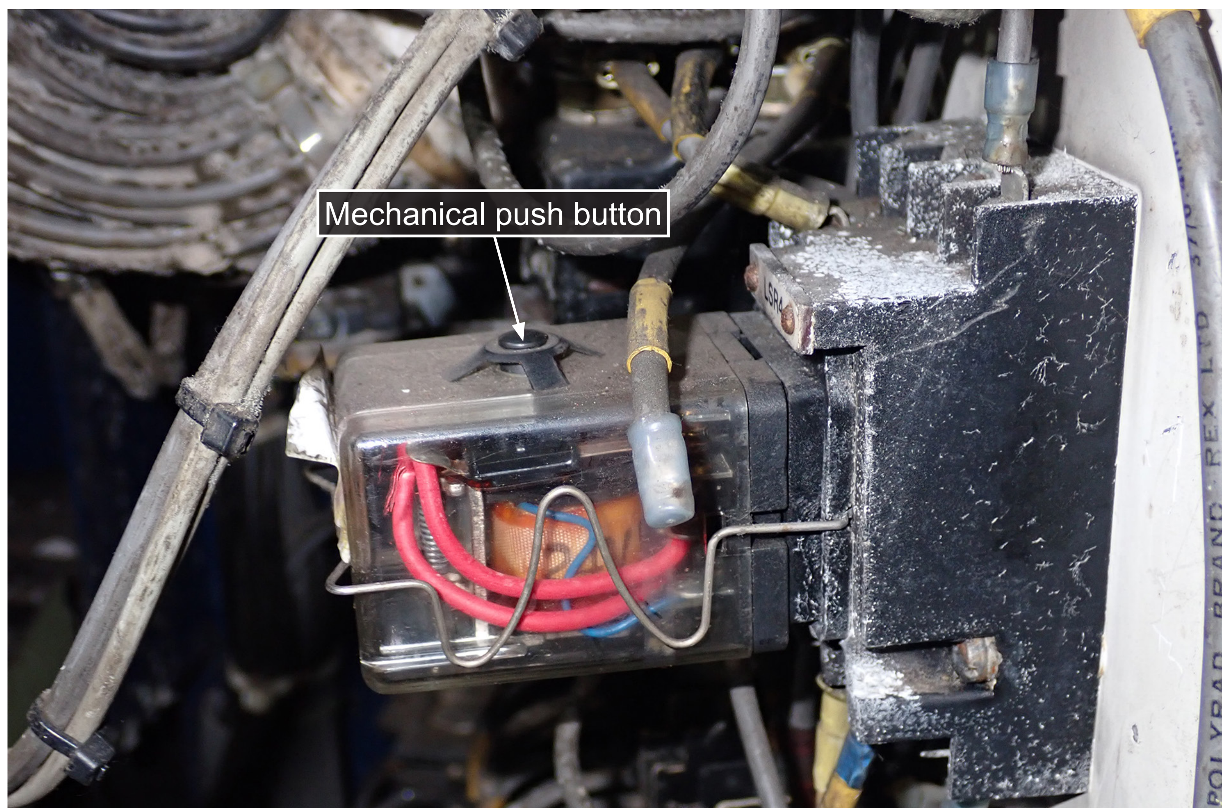

Figure 32: The LSR4 relay correctly seated and restrained in its receptacle base.

170 When this manual override push button was pressed, the normally open contacts closed as expected and electrical current passed through the relevant relay contact, permitting the sanding circuit to function. The LSR4 relay was removed and replaced with another relay of the same type, after which the sand discharge test was performed successfully. Following this successful test, the LSR4 relay and base receptacle were removed by RAIB for further testing.

171 This bench testing of the LSR4 relay found it would function normally without the base receptacle but, when the two parts were assembled, an intermittent failure occurred. This failure was found to be an intermittent break in the coil circuit located between a base contact terminal and the internal coil feed wiring. This break would cause the coil to de-energise when only small amounts of external pressure were applied to the external relay case.

The ability of an electrically active sander to clear a blocked delivery hose

172 RAIB conducted several tests at Machynlleth depot to determine the effects of a blocked delivery hose on working sanders. These tests used a delivery hose which had been modified to include a pressure gauge to indicate the air pressure within the hose at various states of blockage. To simulate different states of blockage, a mechanical valve was fitted to the end of the hose which could be closed in defined increments up to 100% blocked.

173 The results of this testing showed that a fully blocked hose would create a back pressure behind the blockage of approximately 0.5 bar with no air flow to carry sand down the delivery hose. It was also found that air diverted away from the blocked hose would exhaust either through the sand hopper breather vent or through the weather seal around the sand hopper filling flap.

174 To determine whether the blockage found on vehicle 57841 would have been expelled by a correctly functioning sander, RAIB reconstructed the sanding system using the sand hopper and sand valves recovered from vehicle 57841, together with new sand delivery hoses of approximately the correct length. The short sections of blocked sand delivery hose end removed from the vehicle after the accident were then joined to the new sand delivery hose with a back-to-back coupling union. A portable compressor was used to supply the reconstructed sanding system with a similar air pressure to that provided by a class 158 train.

175 The testing was conducted on the fully blocked hose end from vehicle 57841, which had been stored at ambient room temperature for 250 days, and a nearly fully blocked hose end from the trailing vehicle 52841, which had been frozen for 200 days and defrosted before testing. To validate the test rig, the delivery hose used at Machynlleth, which had been modified to measure the pressure generated behind a hose blockage, was connected (paragraph 172). When the sand valve was operated, the test rig produced comparable pressure results to those found during testing at the depot. After this validation, the two sand delivery hoses taken from 158841 were tested in turn.

176 Testing found that the back pressure generated in the sand delivery hoses was sufficient to clear a total blockage, although some material may remain (appendix C).

177 Following the accident, RAIB surveyed other train operators of class 158 units to determine the frequency of any hose blockages requiring intervention by maintenance staff. These operators reported very low numbers of such blockages, with the largest reported number being five hose blockages across a fleet of 18 units during the whole 2024 leaf fall season. The reported blockages required physical intervention by maintainers to unblock the hoses and were attributed to adhesion modifier or, in one instance, a slurry-like substance caused by powdered track ballast originating from a known track defect. None of the operators surveyed reported blockages consisting predominantly of organic material, such as was found on the hoses of unit 158841 (appendix D).

178 The testing undertaken by RAIB was limited by having only two samples, both of which had been in storage for a long period of time before testing. It is possible that the properties of the organic blockage material had changed during this storage period, and it is not possible to say if any changes would have made it easier or more difficult for a functioning sander to expel the blockage.

179 However, the analysis undertaken on the material removed from the non-driver's side hose of 57841 shows the blockage was formed of organic material originating from trees, which is quite different to the material reported by other operators of class 158 trains which required maintenance intervention to unblock the hoses. If organic material from trees was able to form sand hose blockages capable of disabling an otherwise functional sander, it is likely this would have featured more prominently in the feedback received from other operators of class 158 trains.

180 RAIB's testing, in combination with this lack of reports of hoses being blocked with organic material, indicates that organic material which builds up in hoses can be ejected by a normally functioning sander (either when the sander is activated by WSP activity, or when the sander test button is pressed), without necessarily being observed or reported. On this basis, RAIB has concluded that a functioning sander would probably not have allowed the sander hoses to become totally blocked by organic material, as was found on unit 158841 following the accident.

181 RAIB found no electrical defects on the trailing vehicle of train 1J25, vehicle 52841. Appendix D describes the possible mechanism for the sand delivery hose blockage which was found on that vehicle (paragraph 156).

Timeline for the electrical defects on vehicle 57841

182 In the early hours of Friday 18 October 2024, the automatic sanding system of unit 158841 was topped up with fresh sand at Holyhead depot in north Wales when the unit arrived to be stabled overnight. Although TfWRL did not record when and by how much the sanders were topped up, CCTV evidence shows that vehicle 57841 had three 5 kg bags of sand added to the hopper. In normal operation, sand will be consumed by three means:

- the use of the sand hopper test button to discharge sand
- the use of the manual sand button, which is available to drivers to discharge sand when the unit is in traction, and intended to be used in low adhesion conditions (paragraph 83)
- the normal operation of the automatic sanders when demanded by the WSP system.

183 The first means of sand discharge described above (sand hopper test button) would continue to operate even if one or both of the electrical faults described by paragraphs 162 to 171 were present. Therefore, the addition of sand to the unit at Holyhead does not offer conclusive evidence for when the automatic sanders on vehicle 57841 ceased to function.

184 The last time the sanding delivery hoses were known to be clear before the accident was on 20 October, the day before the accident, when the sander test button was used to manually operate the sanders (paragraph 42). However, using the sand test button would have bypassed the probable electrical failures associated with the SIS and the LSR4 relay on vehicle 57841, which means the 20 October test is not indicative of when these faults arose.

185 Unit 158841 had been subject to a 'B' examination at Machynlleth depot on 12 October, 9 days before the accident. This examination included a successful test of the sanding system on both vehicles, triggered by the WSP system. The unit would not have passed the test had the SIS on vehicle 57841 been at high resistance during this exam, meaning that the SIS fault was not present at this time. The time needed for this type of fault to develop and the fact that its development is much more likely when no current is being periodically passed through the contacts means it is more likely to have occurred in the period between the accident and subsequent RAIB testing than between the 'B' examination and the accident.

186 Had the LSR4 relay on vehicle 57841 not been functioning correctly at this time, the unit would have failed the 'B' examination test. However, the intermittent on/off nature of the LSR4 fault means that the relay could have been working at the time of the examination while later preventing the automatic sanding system from functioning before and during the accident.

The effect of a functioning automatic sanding system on the accident at Talerddig

187 WSPER simulations were undertaken to estimate the effect of a functioning automatic sanding system. Two sand delivery rates were modelled in these simulations:

- 2 kg/minute (the maximum permitted by TfWRL maintenance procedures)
- 1.5 kg/minute (the minimum permitted by TfWRL maintenance procedures).

188 These simulations were based on the average adhesion profiles which were generated by the earlier WSPER simulations (paragraph 131) and the speed and braking profiles used were those of train 1J25 as it approached Talerddig loop. The simulations show the effect of a functioning automatic sanding system (figure 33), with the green portion of the braking distance showing the period where the sanding system is automatically activated (that is, when the conditions for automatic sanding are met).

189 These simulations show that a functioning automatic sanding system delivering 2 kg/minute of sand would have enabled the train to stop before block marker MH1078. A train delivering 1.5 kg/minute of sand would have stopped at, or very slightly beyond the block marker, well before there was any risk of its movement conflicting with another train.

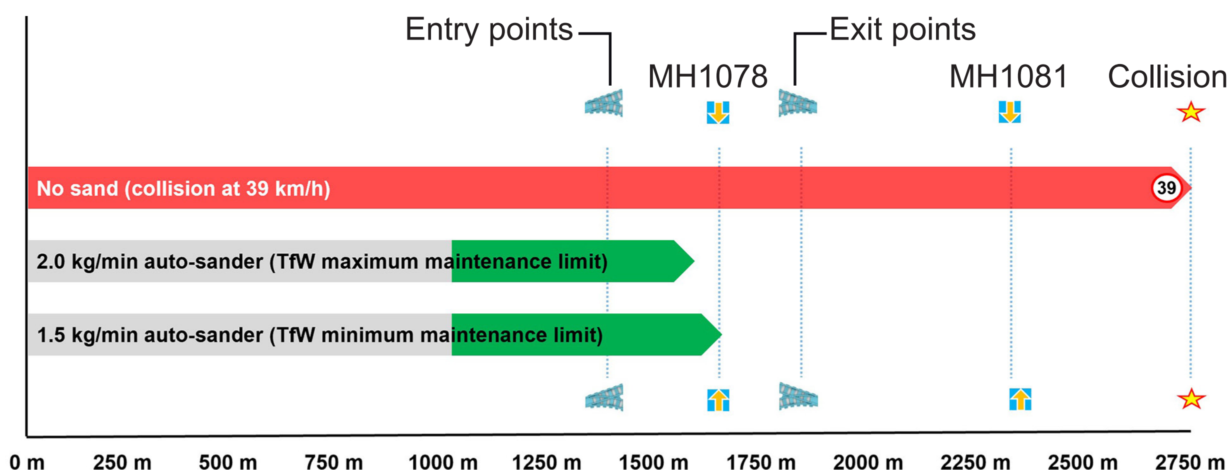

Figure 33: Estimated effect of a functioning automatic sanding system with different sand delivery rates.

Summary of issues associated with the automatic sander

190 The WSPER simulations demonstrate that, had the automatic sanding system on train 1J25 been operational, the accident at Talerddig would have been avoided. This remains true even when a reduced sand delivery rate is considered (see paragraph 397).

191 The fully blocked sand delivery hoses demonstrate that the automatic sanding system on vehicle 57841 did not deliver sand when required. RAIB has concluded that a functioning sanding system would probably clear these blockages (paragraph 180), indicating that a failure other than the hose blockages themselves had occurred.

192 RAIB's testing did not identify any other faults with the WSP processor or the pneumatic part of the automatic sanders which could have prevented the sander from operating. RAIB's testing did, however, identify two faults in the electromechanical sand valve control circuit (paragraphs 162 and 167). If present at the time of the accident, either one of these electrical faults would have prevented the automatic sander from operating. RAIB has, therefore, concluded that the automatic sanding system on vehicle 57841 probably failed to deliver sand when required due to the presence of one or both of these electrical faults. The on/off nature of the LSR4 relay fault makes this the more likely of the two electrical faults.

The emergency sanding system

193 An emergency sanding system is fitted to TfWRL's class 158 units (paragraph 80). This is independent of the automatic sanding system.

194 The emergency sanding system is only available when the train is in an emergency brake setting (either because the driver has made an emergency brake application, or because the ERTMS system has demanded an emergency brake application). In these circumstances, the emergency sanding system is activated by a driver striking a plunger in the cab. This opens valves which vent a powerful stream of compressed nitrogen gas and sand directly at the wheel-rail interface ahead of the leading wheels under each vehicle cab (figure 34). Two pressure vessels are activated simultaneously; once activated, they only stop supplying sand when either the gas pressure is exhausted or the sand supply is used up.

Figure 34: Emergency one-shot sander being deployed; note the powerful jet of sand.

195 The emergency sanding system includes in-cab indicators which are illuminated when the system is healthy (one for the left-hand sander and one for the right-hand sander, figure 35). Train drivers check that these indicators are illuminated as part of their train preparation. No defects were reported during the train preparations which were undertaken on the days before the accident. Due to previous concerns about the indicators being too bright when driving at night, a simple moveable cover was added to reduce glare. When driving at night with the cover down, the indicator lights are still visible but shine less brightly.

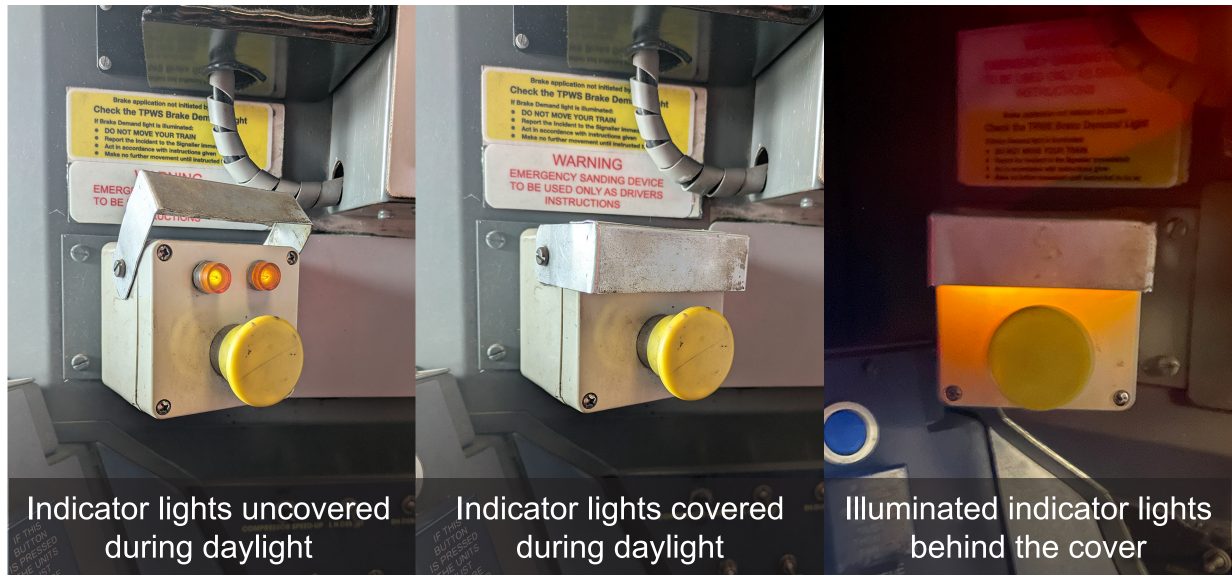

Figure 35: Emergency sander plunger (three images - uncovered and covered indicator lights along with a night-time photograph of the illuminated indicator lights behind the cover).

196 Each pressure vessel has an indicator which shows if the internal pressure is within a defined zone (figure 36). These indicators, which are similar to the indicators on a fire extinguisher, are checked during routine train maintenance. These indicators are only visible from the train's underside and are not routinely checked by drivers.

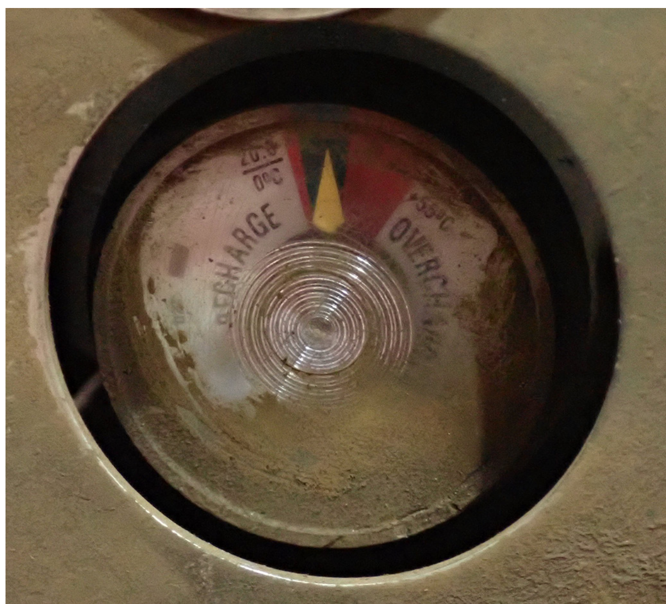

Figure 36: Example pressure indicator on an emergency sander pressure vessel, showing the needle in the green zone.

197 RAIB inspected the emergency sanding system during detailed testing undertaken after the accident. The 'sander healthy' lights on vehicle 57841 were not illuminated, and this was traced to an open (tripped) circuit breaker which provides the electrical supply to the emergency sanding system. This circuit breaker is installed in the roof panel above the driving desk. Although the circuit breaker did not suffer any direct damage, it is located in an area which sustained damage during the collision. RAIB considered the magnitude and direction of the collision forces involved and concluded they were greater than the force required to trip the circuit breaker. This, along with witness evidence that the sander healthy lights were illuminated before the accident, supports a conclusion that the circuit breaker tripped as a consequence of the collision.

198 The pressure vessels on vehicle 57841 were found to be pressurised (with the indicator pointing to the green zone) when RAIB inspected them shortly after the collision. They were still pressurised during RAIB's next inspection of this area 78 days later. After reinstating the tripped circuit breaker, both in-cab indicators for vehicle 57841 were illuminated, showing that the emergency sanding system was healthy. The system discharged sand as expected when tested by RAIB.

The effect of deploying the emergency sanding system

199 Testing indicated that the emergency sanding system would deliver a sand rate of approximately 5.2 kg/minute to each wheel. RAIB tested three such systems and sand was recorded as being delivered for an average time of 37 seconds.

200 WSPER simulations were undertaken to estimate the effect of deploying the emergency sanding system at different geographical locations and times. The WSPER system had an existing emergency sanding model which delivered sand at a rate of 3 kg/minute, and the sanding duration was capped at 30 seconds for the simulations. This sand delivery rate and duration modelled in WSPER is lower than that found during RAIB's post-accident testing; therefore, the emergency sanding system is likely to perform better in reality than in these simulations.

201 The simulations are summarised in figure 37. They estimate that, if the emergency sander had been deployed:

- at the moment that the ETCS system intervened with an emergency brake intervention, when the emergency sander would have first become available (paragraph 194), train 1J25 would have stopped just beyond block marker MH1078
- when passing the intended stopping position at block marker MH1078, train 1J25 would have stopped just beyond the points at the exit of Talerddig loop
- as the train exited Talerddig loop (approximately 18 seconds after passing block marker MH1078), then train 1J25 would have stopped just beyond block marker MH1081 (where train 1S71 had been instructed to stop)
- 75 seconds after passing block marker MH1078,[12] then the collision would probably still have occurred, although the speed of train 1J25 would have been significantly reduced, to around 14 km/h.

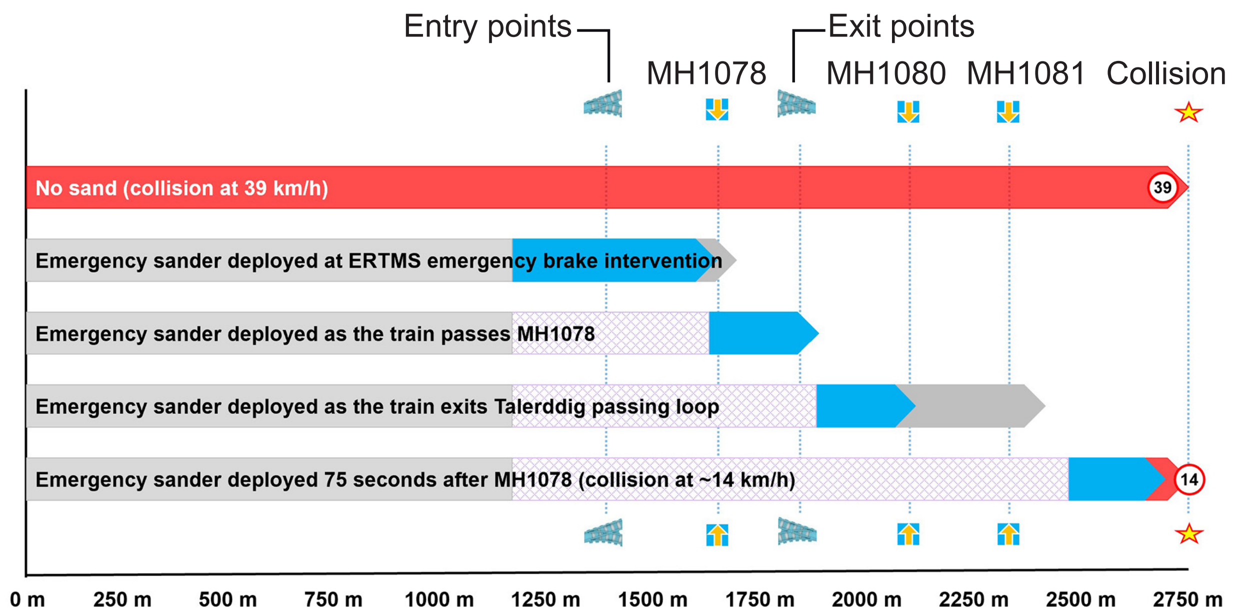

Figure 37: Estimated effect of emergency one-shot sanding system deployed at different locations/times. The purple hatched area indicates when the emergency sander is available, and the blue coloured area indicates the 30 second period of emergency sand delivery.

[12] In this WSPER simulation, the emergency sander is deployed 75 seconds after passing block marker MH1078, which is around 280 metres on approach to the point of the collision. Note that the train driver left the driving cab around 120 metres before the collision (paragraph 59), and therefore would have still been in the cab at the point when the emergency sander was deployed in the WSPER simulation.

Non-use of the emergency sander

202 The railway Rule Book GERT8000 Module TW1 'Preparation and movement of trains', issue 19 dated December 2023 of which was in force at the time of the accident, required drivers to use manual sanders as necessary to assist traction and braking. This guided drivers to avoid deploying sand if they were near to points, travelling less than 12 mph or at a standstill unless '*it will avoid passing a signal at danger, an end of authority (EoA) without a movement authority (MA) or any other serious incident'*.

203 TfWRL's class 158 braking instructions, 'Emergency Sanding Device', issue 2 dated September 2021, requires drivers to use the emergency sander, referred to as an emergency sander device (ESD), stating:

> '*you must only use the ESD when a train is unable to stop in the usual distance and its use may help to avoid one of the following situations:*
>
> - *Signal passed at danger (passing beyond the movement authority on ERTMS signalled infrastructure)*
> - *Collision with a buffer stop*
> - *Collision at a level crossing*
> - *Any other collision or derailment*.'

204 The driver of train 1J25 passed two block markers applying to westbound trains during the overrun. The first was MH1078, located in the loop, which was the end of the movement authority for the train. The second was block marker MH1080, located 259 metres beyond the start of the single line (figure 4). To comply with the Rule Book and TfWRL braking instructions, the driver of train 1J25 should have discharged the emergency sanders on realising the train would pass block marker MH1078.

205 RAIB's investigation found no evidence that the driver of train 1J25 was subject to the effects of fatigue, any pre-existing medical condition or medication, or that they were distracted from the driving task during the accident. The driver of train 1J25 qualified as a driver of class 158 units in March 2022 and had experienced two full autumn seasons as a driver by the time of the accident. They had previously worked as a maintenance technician and gained an awareness of emergency sanders in that role before qualifying as a driver. However, the driver of train 1J25 did not recall any training on the use of emergency sanders and had not previously needed to use them while driving. The driver's training in the use of the emergency sanders is discussed further in paragraph 373.

206 The driver stated that it had not occurred to them to use the emergency sanders on the day of the accident. They recalled thinking that the adhesion conditions would improve, as this was their previous experience of braking in low adhesion conditions. The driver's initial belief was that the train's speed would reduce, in accordance with their expectation of how the train would respond in the situation. This expectation was based on previous experience which had resulted in successful outcomes.

207 Analysis of OTDR data (paragraph 106) shows that the train decelerated at between 3 and 4%g (0.29 and 0.39 m/s²) while it was in Talerddig loop. This is significantly lower than the expected emergency brake rate of 9%g in good adhesion conditions (paragraph 106). The data also shows that the train was travelling at approximately 33 km/h when it left the loop, entered the descending gradient and encountered exceptionally low adhesion, after which the train did not decelerate. If the train had continued decelerating at the same rate as it did while it was in the loop, it could have stopped shortly after entering the single line. This may explain why the train driver believed the train was going to stop without further intervention.

208 People update their assessments and their actions in an evolving situation. Their understanding of a situation may change, and their current understanding will, in turn, affect their attentional focus. Once they made the decision to call the signaller, the driver reported that their attention became focused on this task, and using the emergency sanders at this point did not come to mind.

The driving of train 1J25 on the approach to Talerddig

209 **The approach speed of train 1J25 towards the eastern entry to Talerddig loop was such that the subsequently required deceleration could not be sustained with the available wheel-rail adhesion.**

210 On the approach to Talerddig loop, the speed profile of train 1J25 breached the ETCS intervention profile in advance of the 50 km/h permissible speed (see paragraph 214), causing ETCS to demand an SBI (the equivalent of a full service brake application, paragraph 86). The driver stated that they also made a full service brake application at around the same time. However, in the absence of a functional automatic sanding system, the available wheel-rail adhesion was not sufficient to support the required brake effort needed to comply with the 50 km/h permissible speed which applied to the turnout into the Up Loop (paragraph 154). The train subsequently entered Talerddig loop at around 70 km/h. This additional speed, combined with the continued low wheel-rail adhesion and consequent increase in required braking distance, meant train 1J25 was unable to stop before passing block marker MH1078.

The indications provided to drivers by the ETCS system

211 Drivers on the Cambrian lines are provided with information relating to their journey on the ETCS system's DMI screen (paragraph 35). The DMI provides drivers with a live graphical representation of upcoming features on a rolling display known as the planning area. This indicates features such as the limit of movement authority, gradient and speed profile. The default look ahead range is 4 km, but this can be changed to a user-selected view ranging from 1 km to 32 km (figure 38).

212 In addition to the planning area, the DMI also features a digitised analogue speedometer indicating actual train speed, along with graphical representations of upcoming reductions in speed and the distance to those restrictions. The DMI also incorporates a message area indicating system status, driving modes, and other supplementary information relating to signalling and system status.

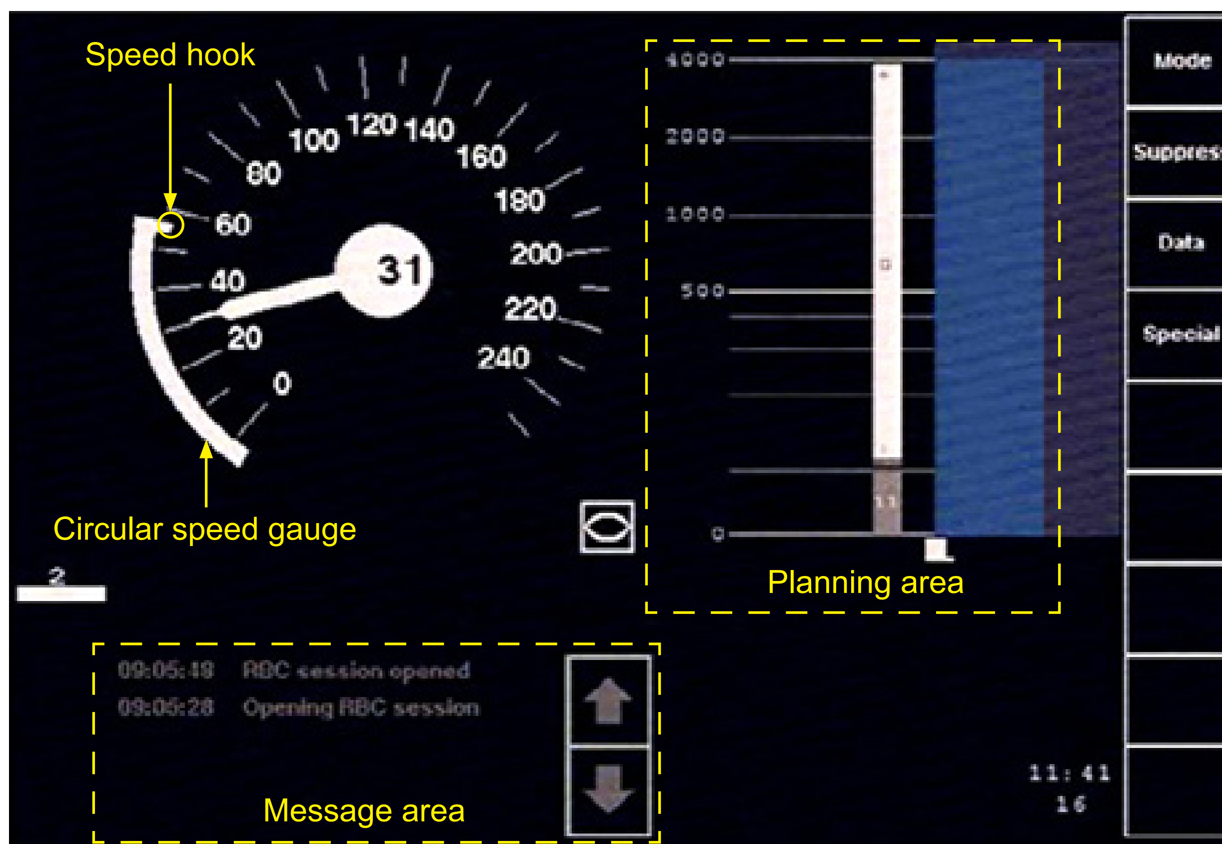

Figure 38: View of DMI screen.

213 The speedometer is overlayed by a graphic known as the ‘circular speed gauge’. This terminates in a ‘speed hook’ at the current permissible speed. As the train approaches a reduction in permissible speed, the speed hook will begin to fall, indicating the need for the train to reduce speed accordingly. The speed hook will move anticlockwise around the speedometer until it reaches the new permissible speed. The hook falls at a rate which, if a train were to follow this deceleration curve, it would arrive slightly ahead of the start of the lower permissible speed travelling at the correct speed.

214 The on-board system constantly monitors compliance with the permissible speed and the deceleration rate needed to comply with upcoming speed reductions. If the train exceeds this speed profile, an SBI is made to automatically reduce the train’s speed. Because the speed hook falls at a rate which approximates to the deceleration curve needed to meet an upcoming speed restriction, an SBI would be triggered around the point the falling speed hook catches up with the needle of the speedometer.

215 The DMI also goes through a series of colour changes with associated audible warnings of increasing urgency to advise the driver of the actions required to stay within the upcoming permissible speed change.

216 Therefore, on the approach to a reduction in permissible speed, the DMI provides a pre-indication to the driver. This changes the colour of the circular speed gauge to white and grey, with the split between these two colours occurring adjacent to the value of the upcoming reduced speed. The on-board system also emits a pair of audible tones to attract the attention of the driver, and a scale appears to the left of the speedometer giving distance in meters to the change in speed (figure 39).

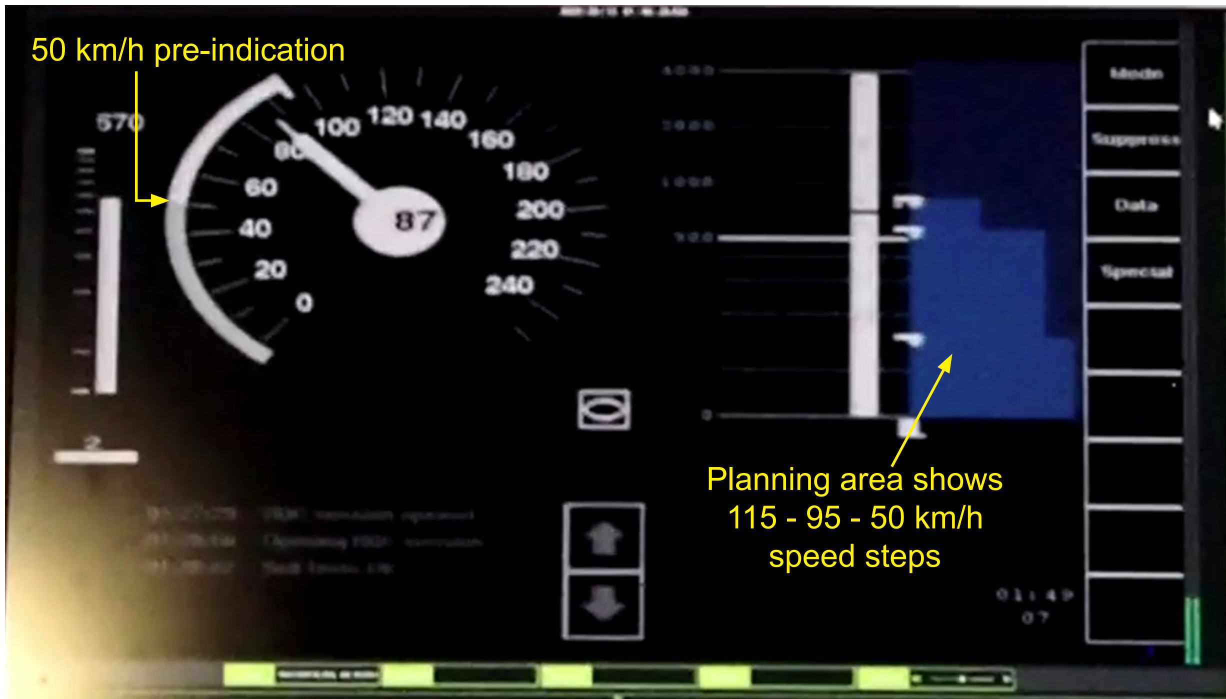

Figure 39: DMI showing white/grey 50 km/h pre-indication, photographed during RAIB test run.

217 Following the pre-indication, a ‘countdown to SBI indication’ appears (figure 40). This is a small box measuring 5x5 pixels positioned above the distance scale. This box grows to give the driver an indication of how close the train is to an SBI. This is calculated according to an algorithm which approximates how close in time the train is to the deceleration curve. The box first appears around 8 seconds before an intervention, growing to 25x25 pixels around 6 seconds before an intervention. If the train decelerates more quickly than the deceleration curve, the box will reduce in size; this gives the visual effect of it seeming to ‘breathe’ in and out, as the driver changes the level of braking.

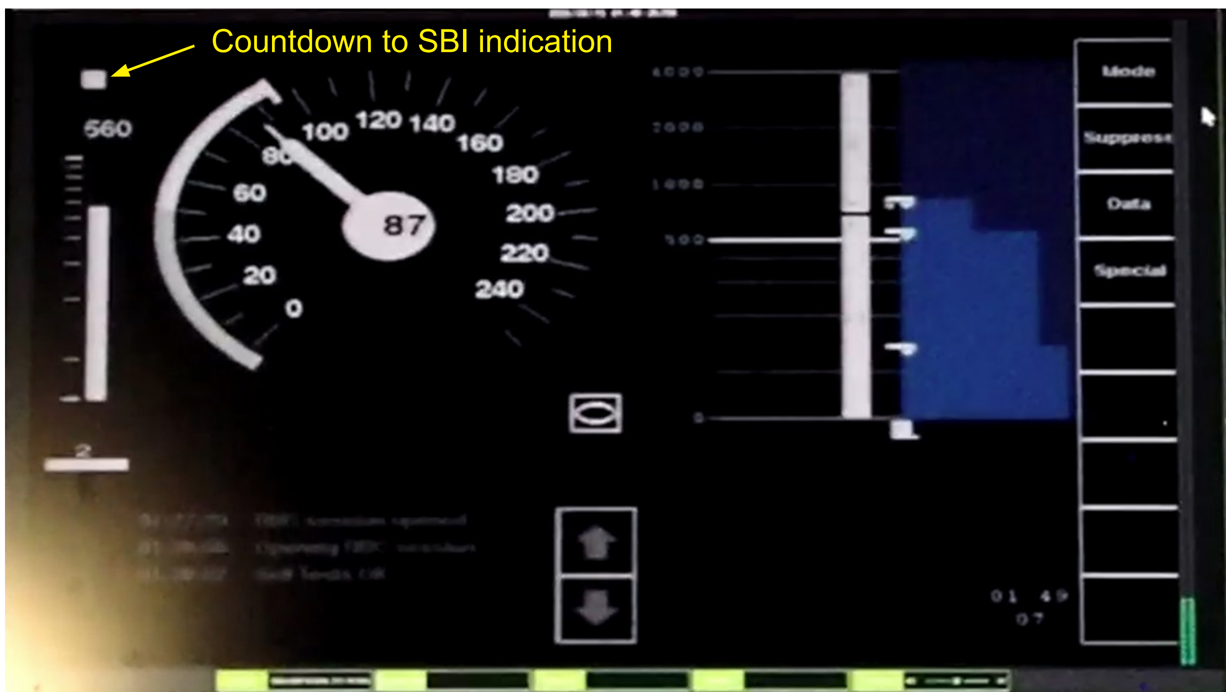

Figure 40: DMI countdown to SBI box, photographed during RAIB test run.

218 When the train reaches the 'indication point', the top half of the circular speed gauge, the analogue speedometer needle and intervention box will turn yellow. This colour change is accompanied by an audible 'warble' and the planning area changing to a greyscale colouring to focus driver attention on the speedometer (figure 41). After receiving this notification, the driver would normally begin braking if they have not already done so as, shortly after this indication point, the speed hook will begin to move anti-clockwise and towards the analogue speedometer needle (figure 42).

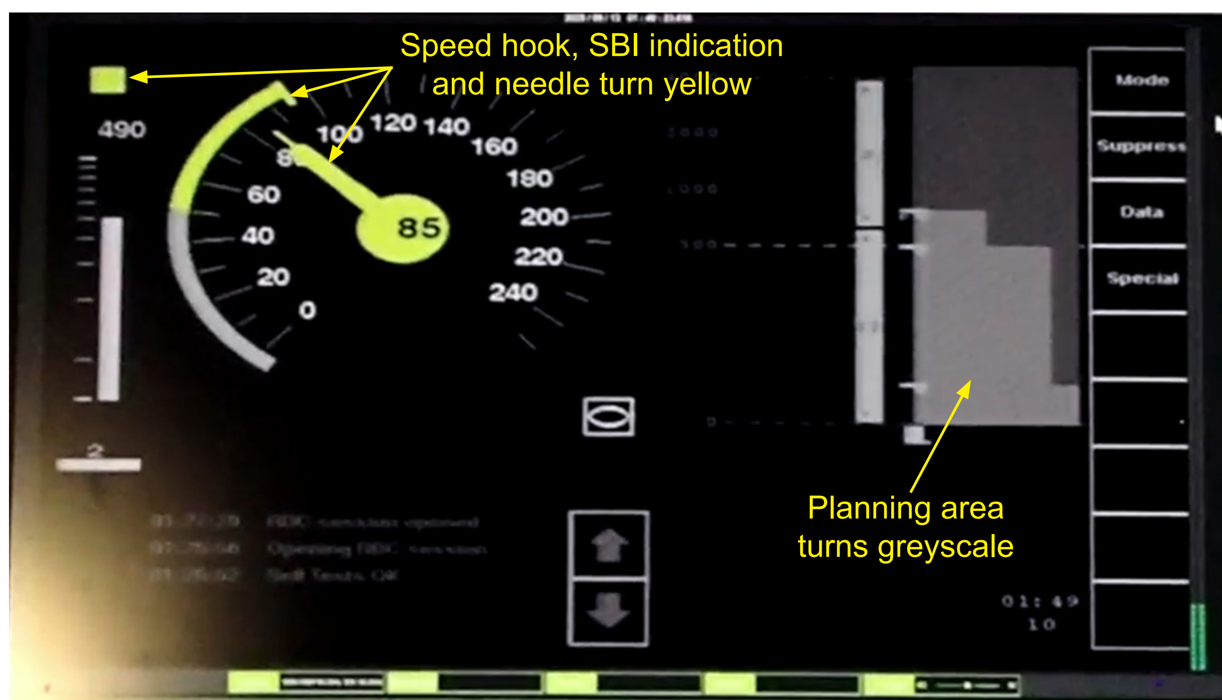

Figure 41: Yellow indication shown on DMI, photographed during RAIB test run.

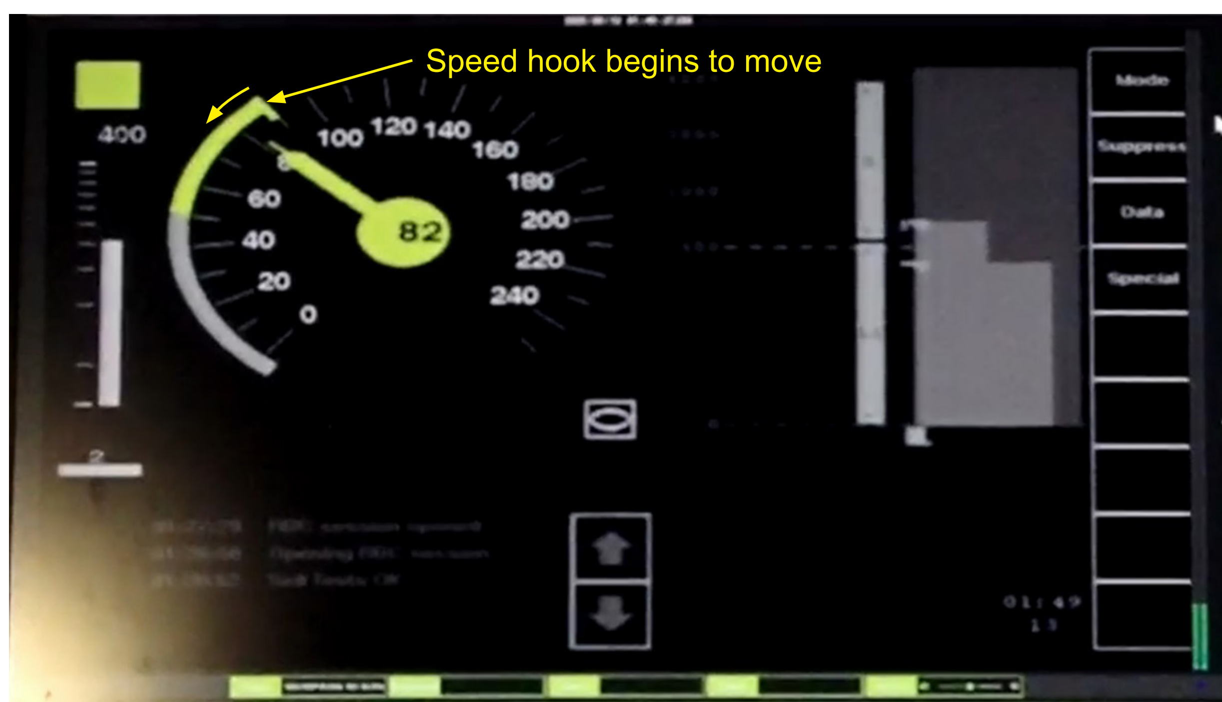

Figure 42: DMI speed hook begins to move down towards speedometer needle, photographed during RAIB test run.

219 If the speed hook reaches the position of the speedometer needle showing the train's speed, the speed hook will turn orange. The box will now have grown to its maximum size of 50x50 pixels. The box will then disappear one second before an SBI occurs (figure 43). This is accompanied by a series of audible warbles. RAIB found documents, including training documentation provided to TfWRL drivers, stating this is the last opportunity for the driver to take action to prevent an intervention. However, during testing undertaken by RAIB, this orange phase lasted around 1 second, by which time it was too late for any preventative action to be taken before an SBI was triggered.

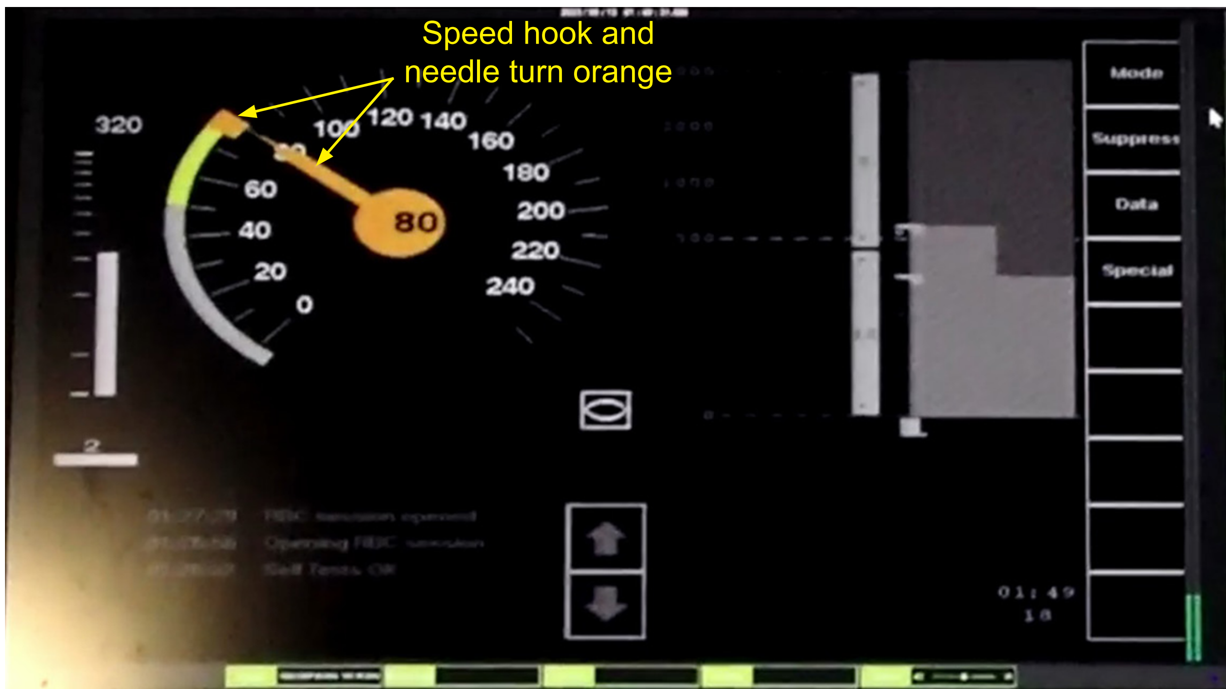

Figure 43: DMI orange warning notification, photographed during RAIB test run.

220 At the point of intervention, traction power is cut and full service braking will automatically apply, the speedometer needle and speed hook turn red, and the audible warnings cease (figure 44). The SBI is indicated by a brake symbol in the DMI message area, with the driver being unable to release the brakes. If the speed of the train reduces to a suitable margin below the required deceleration curve, then the system resets to the yellow indication state and full control of the train is handed back to the driver. The system records this intervention within the JRU; however, an SBI does not require the driver to bring the train to a stand or make a report to the signaller. The fact that the brakes were demanded by ETCS is not recorded by the OTDR.

221 If the train fails to decelerate sufficiently with the automated SBI and exceeds the deceleration curve by a larger amount, the system will trigger an emergency brake application. Unlike some other types of train, class 158 units do not apply any greater braking effort when an emergency brake application is made (paragraph 86), but this intervention is non-revokable and will continue until the train is brought to a standstill. The driver must contact the signaller to report an emergency brake intervention and obtain permission before proceeding. This is analogous to a Train Protection and Warning System (TPWS) brake demand occurring on the mainline railway network on non-ETCS lines.

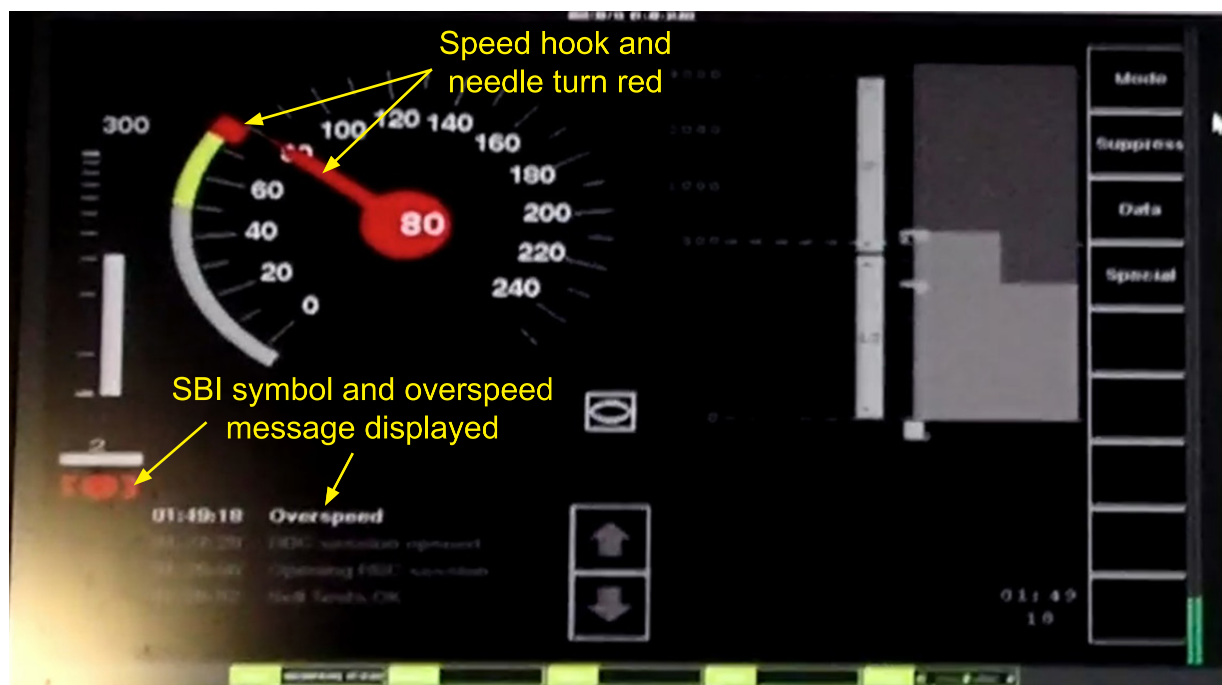

Figure 44: DMI screen at point of service brake intervention, photographed during RAIB test run.

The warnings provided by ETCS to the driver of train 1J25

222 ETCS calculates the timings for the various indications and warnings based on the speed and location of the train and the prevailing gradient and permissible speed profile. The timings are varied using these parameters to provide drivers with consistent notifications based on time rather than distance, as would be the case with the lineside signals and indicators found on conventionally signalled lines. The Cambrian ERTMS system does not record when the various driver notifications occur after the pre-indication point, and so RAIB was unable to directly establish which notifications the driver of train 1J25 received, and at what point these occurred.

223 TfWRL was unable to provide typical timings for the notifications and a review of the training material provided to drivers showed inconsistencies about what information drivers could expect to receive. For this reason, RAIB ran a series of tests during a possession of the line approaching Talerddig. Due to constraints of access, this was limited to three test runs.

224 There are two reductions in permissible speed when approaching Talerddig in a westbound direction, as train 1J25 did. From a permissible line speed of 130 km/h, the speed reduces to 115 km/h, 989 metres on approach to the points at the entry to the loop and reduces again to 95 km/h, 421 metres from these points. For trains taking the route into the Up loop, a third reduction in speed is necessary to comply with the 50 km/h speed reduction which starts at the loop entry points.

225 The three test runs were undertaken with the test driver requested to approach Talerddig at 95 km/h to avoid the potential for a failed test due to an early intervention. When compared together, the test runs indicate a general consistency in the timings of each DMI notification. Small variations are caused by the continuous recalculation necessary to adapt to changes in speed as the train approached the loop (table 2).

226 It was noted that, even at this reduced approach speed, the notifications began to merge such that, as the train passed the start of one restriction, the system would begin the warning process for the next. In one instance, the system intervened with an SBI when the speed of the train had exceeded the 95 km/h permissible speed, and this had the effect of overriding the initial notification of the upcoming 50 km/h restriction.

227 It can be seen in table 2 that the intervention ‘masked’ the initial notifications and went directly to the yellow indication shortly before the speed hook began to move. Because of this, the pre-indication point was not recorded and initial transition to yellow indication and the associated audible warning were not provided.

DMI Event	Run 2	Run 3	Run 1	Train 1J25	
	Time to service brake intervention (s)				Brake step
Grey/White pre-indication	15.3	14.4	Notifications Masked		BS1
Countdown to SBI appears	11.1	10.6			BS1
Yellow indication	8.7	8.7			
				8.6	Coast
Speed hook begins to move	6.0	5.4	6.0		Coast
				3.1	BS2
Orange warning	0.6	1.2	0.6		BS2
Service brake intervention	0	0	0	0	SBI

Table 2: Results of RAIB testing to determine timings of DMI notifications and comparison to the handling of train 1J25.

228 Using the SBI as the reference datum, RAIB has compared the timings obtained during these tests to OTDR data from train 1J25 on the day of the accident. This shows the DMI notifications that the driver would probably have seen and when these would probably have occurred on approach to Talerddig loop (table 2).

229 During testing, it was noted that, as the 95 km/h notification sequence ended, that is, at the start of the 95 km/h speed restriction, the DMI would immediately show the white and grey pre-indication for the upcoming 50 km/h loop speed restriction. This testing was undertaken at a lower approach speed than that of train 1J25. Therefore, it is likely that, on the day of the accident, the DMI changed to the 50 km/h notifications later in this sequence than shown in table 2.

The driving of train 1J25

230 On the approach to Talerddig, the driver of train 1J25 was actively controlling the speed of the train to accurately meet the 130 km/h and 115 km/h speed restrictions. This indicates the driver was aware of their location and actively engaged with the driving task.

231 The driver made two brake step 1 applications ahead of the change in permissible speed from 115 km/h to 95 km/h on the approach to Talerddig loop (paragraphs 52 and 104). After the second period of braking, the brake was released when the train was travelling at 100 km/h and the driver allowed the train to coast where it continued to slow due to the ascending gradient towards the 95 km/h restriction.

232 RAIB ran a WSPER simulation to determine the outcome had the driver of 1J25 maintained brake step 1 without any period of coasting and with a similar application of brake step 2, followed by the SBI, as seen on the night of the accident. This simulation showed that with this additional brake step 1 application, in the absence of functional automatic sanders, the train would have entered the loop at approximately 58 km/h and stopped around 30 metres beyond block marker MH1078. Therefore, compliance with the 50 km/h permissible speed associated with the turnout into the Up Loop and avoiding the need for the SBI would have resulted in the train stopping within the loop.

233 The comparison in table 2 shows that the driver of train 1J25 probably moved the brake controller into coast 6 to 7 seconds after the warning notification sequence for the upcoming 50 km/h restriction should have begun. This would also coincide with the timing of the yellow indication and associated audible warning being triggered. However, it is possible that the driver did not receive this yellow warning notification due to it being masked.

234 The period of coasting lasted for approximately 5.5 seconds, after which the driver made a brake step 2 application, and the train passed the start of the 95 km/h restriction. Shortly after this, ETCS intervened with an SBI. This intervention occurred because ETCS had calculated that the train was travelling too fast to be within the 50 km/h permissible speed when it reached the loop entry points, without a full service brake application. Although the driver reported they had also made a full service brake application, limitations in the way the OTDR monitors braking means that the timing of this cannot be confirmed (paragraph 53).

235 The driver stated that they were aware on approach to Talerddig that the train was being routed into the Up Loop, and that this would mean encountering a 50 km/h speed restriction. They could not account for the excess speed which necessitated the SBI, but were aware that, until the SBI, the train had not encountered any WSP activity (paragraph 88).

236 The driver also stated that the first time that they were aware of the need to further reduce speed for the Up Loop 50 km/h restriction was the yellow speed hook descending towards the analogue speedometer needle with no recollection of an audible warning. This would align with RAIB’s testing, where the DMI switched from the 95 km/h sequence straight into the yellow indication for the Up Loop, shortly before the speed hook began to move. If the train had been signalled along the faster route through the Down Loop, the DMI would have changed from yellow to white and the 50 km/h restriction would not have appeared in the planning area.

237 RAIB has reviewed OTDR records for 19 previous trains routed westbound through Talerddig over a 16-day period before the accident (figure 45). These trains were operated by 14 different drivers. This assessment focused on comparing the actions of the other drivers to those of the driver of train 1J25 when the brake step 1 was released for the second time and the train began to coast.

238 Of these 19 trains, 3 have not been considered because of their lower approach speed or because the way they were being driven did not make them suitable for comparison. Of the remaining 16 trains, the 5 which were required to stop in the loop continued to apply their brakes after the start of the 95 km/h speed restriction without any period of coasting. In contrast, the drivers of the 11 other trains released their train's brakes around the same time as the driver of train 1J25 did on the day of the accident. These trains were not due to stop in the loop. They were also routed through the Down Loop and so were not subject to the 50 km/h speed restriction which applied to train 1J25 on the day of the accident.

239 Although this comparison uses a small sample of drivers, it indicates that train 1J25 was being driven on the day of the accident in a manner similar to that adopted by other drivers when following the higher speed profile through the Down Loop.

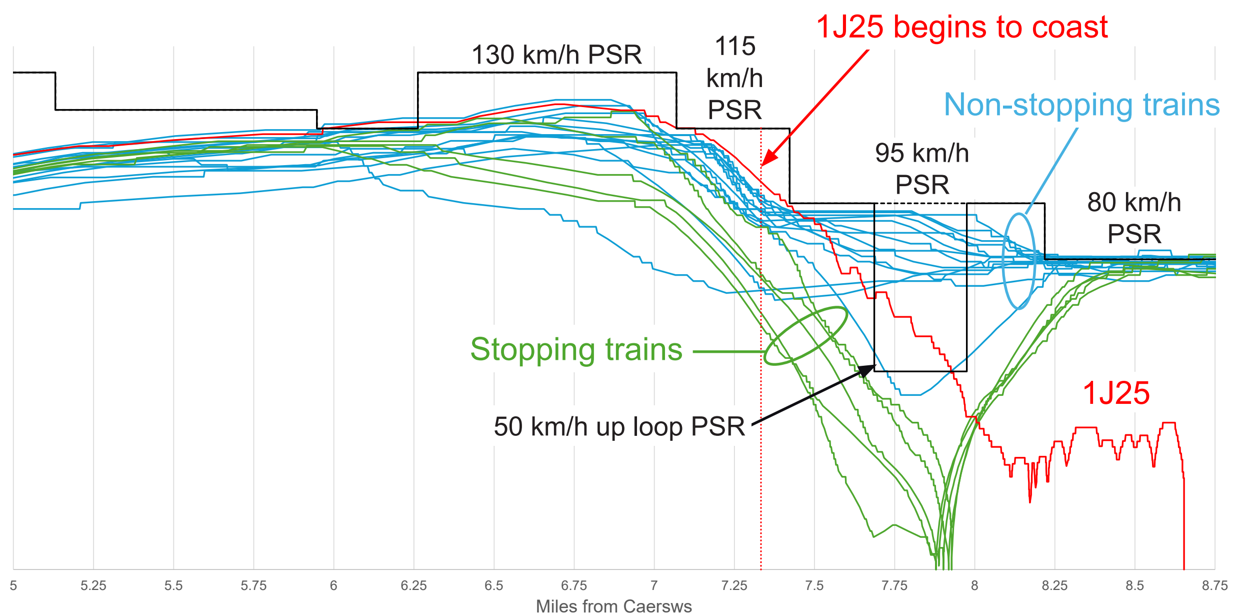

Figure 45: Comparison of the handling of train 1J25 to other trains approaching Talerddig loop.

240 The concept of a speed restriction warning masking notifications for the next one was identified during the early testing phases of the Cambrian ERTMS scheme, when the previous train operator was responsible for operating trains on the Cambrian lines. The Office of Rail and Road (ORR, the safety authority for the railways in Great Britain) raised concerns relating to this potentially causing drivers to mishandle trains and advised the project to avoid closely spaced cascading speed restrictions. RAIB has not been able to establish what action was taken as there is no record of a formal response to this concern (see paragraph 411).

241 Research[13] has shown that driving behaviour under ERTMS can also lead to a reactive style of driving. On conventionally signalled railways, a driver's primary source of information to allow planning ahead is obtained by observing and reacting to visual cues outside the train. By contrast, ERTMS means that the source of information to plan ahead is now primarily found within the cab. This means that a driver may be more reliant on alarms and warnings, rather than a more anticipatory style, with the driver planning actions (based on their knowledge and training) in advance of any system-generated indications.

The single line beyond block marker MH1078

242 Having passed block marker MH1078, train 1J25 entered the occupied single line.

243 After passing block marker MH1078, train 1J25 continued onto the single line with an emergency brake application still in place due to the ETCS intervention. The automatic sanding system remained inoperative. The emergency sanding system was available but was not deployed by the train driver (paragraph 201).

244 Historic records of the gradients on the Cambrian lines, corroborated by a detailed survey of the accident site by RAIB, show that after leaving Talerddig loop train 1J25 encountered a descending gradient of approximately 1:56 which continues to the collision location and beyond (figure 46).

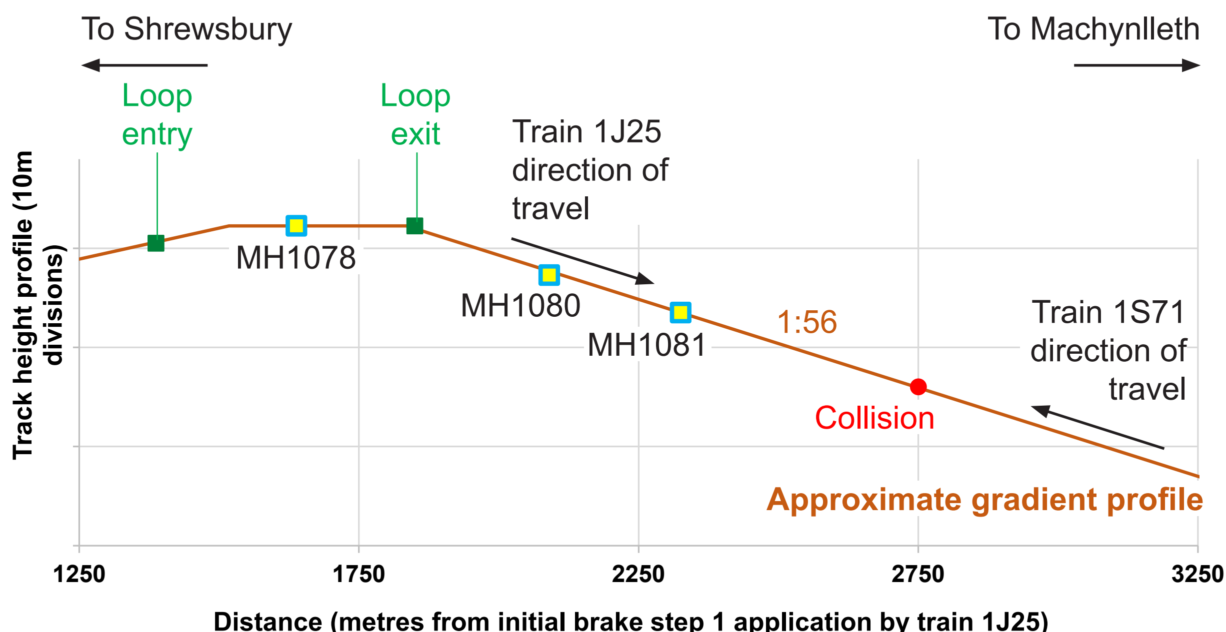

Figure 46: The track descends on a 1:56 downhill gradient after exiting Talerddig loop.

245 As the train progressed further along the descending gradient, on-train data shows that it did not decelerate despite the continuous emergency brake demand. This demonstrates that the available braking was balanced by the train's inherent acceleration due to gravity as it descended the gradient.

[13] Naghiyev and others, 'Alerts and Alarms in Conventional and ERTMS Train Driving: An Exploratory Eye-Tracking Field Study', Proceedings of the Human Factors and Ergonomics Society 58th Annual Meeting, 2014.

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

- The wheel-rail adhesion beyond block marker MH1078 was exceptionally low (paragraph 247).
- No engineered mitigations existed to prevent train 1J25 entering the occupied single line (paragraph 257).

Each of these factors is now considered in turn.

The level of wheel-rail adhesion beyond block marker MH1078

247 **The wheel-rail adhesion beyond block marker MH1078 was exceptionally low.**

248 An examination of the railhead in the area beyond block marker MH1078 was carried out on the day after the accident. Light contamination was observed in several areas, particularly on the descending gradient leading to the collision location (figures 47 and 48). Paragraph 124 describes how samples from the railhead were analysed.

Figure 47: Example of visible contamination observed on the railhead on 22/10/2024 (the day after the accident) on the descending gradient at 100 metres (left) and 200 metres (right) before the collision location.

Figure 48: Example of visible contamination observed on the railhead, at around 10:20 on 22/10/2024 (the day after the accident), after the loop on the descending gradient at 500 metres (left) and 600 metres (right) before the collision location.

249 WSPER simulations were used to estimate the adhesion conditions encountered by train 1J25. This concluded that the average adhesion was low on approach to block marker MH1078 with an estimated peak μ value of 0.06 (paragraph 132).

250 Beyond block marker MH1078, the WSPER simulation estimated that the adhesion would remain low for a further 300 metres (200 metres with peak μ = 0.06, followed by 100 metres with peak μ = 0.05). It would then become exceptionally low (peak μ = 0.035) for the remaining 812 metres up to the point of collision (paragraph 74). This is shown in table 3, and is also shown graphically with other track features in figure 27.

Start location (m)	End location (m)	Peak Adhesion profile (μ)	Notes
0	1838	0.06	From simulation start point to 200 metres beyond MH1078
1838	1938	0.05	The next 100 metres of track
1938	2750	0.035	Remaining 812 metres to collision location

Table 3: The average adhesion profiles used in the WSPER simulations which provided the closest match to the speed profile recorded by the data recorder of train 1J25.

251 During the GSM-R call between the signaller and the driver of train 1S71, which was then ascending this gradient (paragraph 55), the driver mentioned that the train was struggling with low adhesion. However, neither this driver, nor any other drivers, felt that conditions were sufficiently exceptional for the location to make a specific report of low adhesion (paragraph 142).

High risk of low adhesion area

252 Network Rail's operational publications identify an area starting towards the western end of Talerddig loop as a high risk of low adhesion area (HRLA). The start of the HRLA is marked with a lineside sign, positioned in the cess of the Down Loop (but applicable to both lines) just beyond block marker MH1078 (figures 15 and 49). The HRLA site continues down the gradient, beyond the collision location and onwards towards Machynlleth, for a total of 5.9 km.

253 The precise history of the HRLA designation in this area has not been identified by RAIB from the available evidence, although it is known to have been designated as an HRLA for many years. Network Rail reported that the site was designated as a high risk site due to repeated challenges with trains struggling to successfully ascend the incline when travelling from Machynlleth towards Talerddig, including incidents where trains had needed to return to Machynlleth.

254 TfWRL produced an 'Autumn seasonal risk guide' for train drivers, issue 2 dated September 2023, which also identified the HRLA site at Talerddig. Due to the high risk of low adhesion a traction gel applicator (TGA) is provided within the HRLA, along the route taken by train 1J25. This, and its possible effect on the accident, is discussed further at paragraph 288.

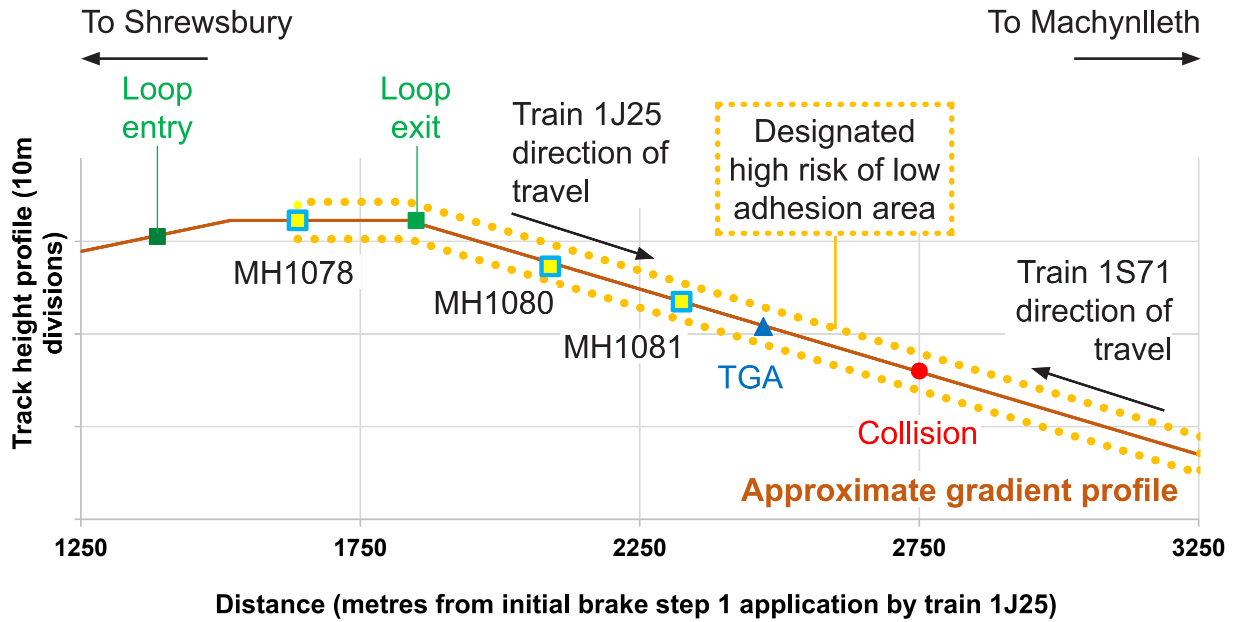

Figure 49: The area of known low adhesion (outlined yellow) and the location of the traction gel applicator (blue triangle), superimposed on the track height profile (brown) and significant features.

255 After leaving Talerddig loop, the single line passes through a deep cutting with vegetation on the side slopes (figures 50 and 51). Because this area was identified as an HRLA, Network Rail designated it as one which would be proactively inspected by ARTs (paragraph 141) during the leaf fall season (appendix E).

Figure 50: Lineside vegetation, in vicinity of the exit points of Talerddig loop at around 09:20 on 22/10/24 (the collision location is approximately 900 m away).

Figure 51: Lineside vegetation approximately 530 m from the collision location.

256 Between 13 September 2024 and 15 October 2024, Network Rail engaged a contractor to remove vegetation at the cuttings between the loop and the accident site in preparation for work to ensure the stability of the rock cutting faces. The results of this work were documented in reports by the contractor which include photographs showing that vegetation in the rock cuttings had been almost completely removed before the accident.

Overrun protection

257 **No engineered mitigations existed to prevent train 1J25 entering the occupied single line.**

Trap points

258 Once train 1J25 had overrun block marker MH1078, there were approximately 81 metres of the Up Loop line left until the two lines converged at the exit points at the west end of the loop. The train, still braking and travelling at approximately 33 km/h, ran through (and damaged) these points before entering the single line. This brought it into the path of train 1S71 which was approaching from the opposite direction.

259 The railway line through Talerddig was opened in 1862, with a signal box provided to control the loop around 1873. By 1950, the signalling was altered so that the Up Loop became bi-directional. In this period, there were no trap points at the west end of the loop, although these were provided at the east end. Trap points are a method of overrun protection using a set of points to divert vehicles away from main lines by deliberately causing a derailment. They are provided in locations where there is a foreseeable risk that a low-speed unauthorised movement might occur, typically at the exits from depots, yards and sidings. As an example of this, a single set of trap points are provided at Talerddig to protect the passenger lines from a potential runaway movement of a vehicle which has been stabled in the refuge siding provided at the east end of the loop (figure 4).

260 Signalling sketches provided by the Signalling Record Society show how the track layout at Talerddig has had many changes since the late 1800s. Trap points at the western end of the loop were provided as part of signalling alterations which took place in 1968. These trap points were removed in 1986 when the track layout was prepared for resignalling using the Radio Electronic Token Block (RETB) system. No changes to the track layout were made when the ERTMS system was commissioned, although the points were converted to power operation (paragraph 15) in place of the train-operated points used under RETB.

261 Because the use of trap points involves intentionally derailing rail vehicles, their use is limited to very specific circumstances. They are, in broad terms, only used if other risk reduction measures are not considered sufficient, and if the secondary risks of the derailment are low. For this reason, they should guide vehicles away from other lines, structures, and hazards, and include a suitable way to arrest the movement of the vehicle(s) involved. On Network Rail infrastructure, their use is generally only permitted at the exits of depots, yards or sidings where the potential derailment speed, and therefore the risk from a derailment, is much lower. The nature of such movements is that they would not ordinarily be made by trains with passengers on board.

262 The track layout and operational use of the loop at Talerddig are such that the specific circumstances which would require the application of trap points are not met. For this reason, with the exception of the trap points protecting the passenger line from an unauthorised movement from the refuge siding at the east end of the loop, trap points are not provided at Talerddig.

Overrun risk assessment

263 Railway Group Standard GI/RT7006, ‘Prevention and Mitigation of Overruns – Risk Assessment’, issue 1 was published in December 2000. Its purpose was to define the requirements for risk assessment of the design and operational use of track and signalling ‘*so as to control the risks associated with trains exceeding the end of their movement authority*’.

264 The standard required that any risk assessment undertaken would include consideration of a driver misjudgement of braking. Primarily, this risk would be managed on conventionally signalled areas by the provision of an overlap. This is a section of track beyond a stop signal which is proven to be clear as part of the controls on approach to the signal. In this way, any minor misjudgement in braking would be protected for as long as the overrunning train stops within the overlap distance, which is normally 180 metres.

265 When driving on a line equipped with ETCS, the drivers of trains are permitted to approach, but not allow the front of their train to pass, the end of movement authority block marker. The ETCS on the Cambrian lines incorporates an allowance for trains passing this block marker. This is also called an overlap, although its function is different to the overlap used with conventional lineside signalling. ETCS relies on odometry and Doppler radar to calculate the position of a train since it last passed the fixed position of a track balise (paragraph 31). The calculation of the train's position incorporates a tolerance for error which grows as the train travels further away from this last balise. This error tolerance is managed within the system by adding a 'virtual length' ahead of and behind the train's actual position. This continues until the train passes the next balise, which resets the error tolerance back to the correct train length.

266 However, the positioning error might place the front of the train beyond the block marker and cause ETCS to trigger a spurious emergency brake application. To prevent this false tripping, the system allows what it understands to be the position of the train, including the potential error, to pass the end of movement authority. The system supervises both the speed and distance of this action to ensure that, even up to the maximum positional error, the train remains within the overlap.

267 In the case of MH1078, the ETCS overlap distance beyond the block marker was 81 metres for passenger trains, much less than the normal 180 metres required by Railway Group Standard GK/RT0064, 'Provision of Overlaps, Flank Protection and Trapping', issue 1, dated December 2000 of which was in force when the Cambrian lines was resignalled. The ERTMS project responsible for the system was granted a derogation in September 2009 from the requirement to provide a full overlap on the basis that ETCS would constantly supervise the train and hence prevent an overrun beyond the overlap.

268 An overrun risk assessment would initially consider whether it is possible to mitigate or minimise the potential for a collision to occur using the track layout to divert the overrun away from other trains. This is normally followed by a detailed assessment which considers the likelihood, extent, consequence and probability of an overrun resulting in a collision. However, GI/RT7006 allowed a simple overrun risk assessment to be undertaken for low-risk signals when set criteria were met. Lines equipped with automatic train protection systems, such as ETCS, are required to meet the following criteria to avoid the need for a detailed assessment:

- '*The signal and associated preceding caution signal(s), and the associated Automatic Warning System (AWS[14]) equipment, are compliant with the requirements of the railway group standards that are in force at the time of the risk assessment and which are relevant to the control of overrun risk.*
- *The action of the train protection system and, where applicable, the setting and interlocking of facing points ahead of the stop signal, is such that all trains overrunning the stop signal will be routed so as to avoid, or be brought to a stand short of, all areas of conflict and all infrastructure features that could either increase the likelihood of a collision or could significantly worsen the consequences of a collision or derailment.*

[14] AWS is a system which provides a visual and audible indication of signal aspects to drivers on conventionally signalled mainline railway lines in Great Britain. It is not fitted on the Cambrian lines, having been superseded by the fitment of ETCS.

- *The action of the train protection system is such that all trains overrunning the stop signal will be brought to a stand so as to avoid a rear end collision with a train standing at a stop signal ahead (this criteria has to be met in respect of all routes that the train might follow after overrunning the stop signal under consideration).*
- *The action of the train protection system is such that all trains overrunning the stop signal will not derail on any points or crossings ahead (this criteria has to be met in respect of all routes that the train might follow after overrunning the stop signal under consideration).'*

269 A simple overrun risk assessment was prepared for the deployment of ERTMS on the Cambrian lines. This document was titled 'Overrun Risk Assessment ERTMS Level 2 Movement Authorities Cambrian EDSCL-DES-004000', revision 0.2, issue 10, and dated January 2008. This seven-page document takes the form of a simple generic risk assessment covering all the Cambrian lines without consideration of any specific location. This document justifies the use of a simple risk assessment against GI/RT7006 clause 4.4 b i because:

- *'Railway group standards relating to lineside signals do not apply to in-cab signalling systems.*
- *The Cambrian ERTMS system does not use AWS equipment.'*

270 Guidance to GI/RT7006 clauses 4.4 b ii and iii was provided in GI/GN7606, 'Guidance Note: Prevention and Mitigation of Overruns – Risk Assessment', issue 1 dated December 2000. This stated that, for a signal fitted with automatic train protection to qualify as low risk, the train protection system concerned must:

- '*be fitted and operational on all trains authorised to operate on the route.*
- *enable the criteria to be met in respect of all types of trains authorised to operate on the route, taking account of the permissible speed(s) and braking performance of each type.*
- *be functional (i.e. capable of stopping an overrunning train) for at least 99% of the time that the system is required to be in service. This applies to both the track-based and trainborne equipment*.'

271 The overrun risk assessment for the Cambrian ERTMS resignalling stated that only equipped trains for which the application design had considered the braking performance and permissible speeds would operate on the ERTMS lines. The risk assessment also quoted the maximum allowable rate for an exceedance of the permissible speed or distance to be $2x10^{-9}$/hour/train. The assertion was, essentially, that no train supervised by ETCS could overrun the overlap provided.

272 The absence of a detailed risk assessment meant that the unique combination of overrun risks beyond MH1078 such as the HRLA site, steep downhill gradient and entry to a single line were not considered. A better understanding of these features may have identified the need to prevent an overrun reaching the single line section either by increasing the overlap distance or applying controls to reduce the speed of an approaching train before it reached the loop.

Factors affecting the severity of consequences

Collision speed: the continued movement of train 1S71

273 **Train 1S71 was permitted to proceed to the end of its issued movement authority.**

ETCS movement authority for train 1S71

274 Train 1S71 had been issued movement authority to block marker MH1081 which only applies to eastbound trains. It is normal for the route beyond a block marker to be set, or reserved, ready for an approaching train. As a train approaches, it requests the route ahead and, if it has been set and remains available, the movement authority is issued. When train 1J25 passed the end of its movement authority, the route beyond MH1081 had been set, but the movement authority had not yet been issued to train 1S71. As train 1J25 approached the single line, its occupation of the track over the loop exit points meant the set route beyond MH1081 was no longer available to be issued to train 1S71.

275 ERTMS does not incorporate a function to automatically send a stop command to trains with movement authorities already issued where the overrun is not in direct conflict with their route. Even though train 1J25 had entered the single line and was now foul of the single line, it had not passed MH1081, so was not yet in conflict with movement authority issued to train 1S71. The provision of a facility to automatically send a stop command to trains with a valid movement authority in the event of an overrun without a direct conflict would be subject to a client requirement. Client requirements are a method of requesting specific functionality of a software product, such as the ERTMS system, which would not otherwise be provided by default. This request would have originated from Network Rail but was not made, so the facility was not provided on the Cambrian lines.

276 The signaller is provided with an Area Emergency Stop function, which would send a 0 km/h temporary speed restriction command to all trains in the area. This would have caused train 1S71 to come to a stop. Although this function is available, the system requirements specification for the Cambrian ERTMS installation states that the priority action for signallers requiring trains to stop in an emergency is to use the GSM-R radio system.

The use of GSM-R

277 GSM-R provides train drivers with the facility to make a REC call. Such a call is broadcast to signallers and to the drivers of other trains in the area. Signallers may also make REC calls using GSM-R.

278 Rule Book GERT8000 module TW1 (paragraph 202) states to train drivers:

‘*You must only use the emergency call facility when it is necessary to give immediate advice for trains to be stopped or cautioned, or to call the emergency services, in connection with an accident, obstruction or other exceptional incident.’*

The same Rule Book module also states:

‘If you receive a REC, you must:

- bring your train to a stand immediately
- listen to the message.’

279 Drivers of trains on ETCS-signalled lines do not have visibility of the location or movements of other trains on their DMI. It will only show the extent of the movement authority for their train and the line speed applicable to their route ahead. Although the driver of train 1S71 was expecting to pass another train (1J25) at Talerddig loop, the drivers were not in direct contact. Therefore, the driver of train 1S71 was unaware that train 1J25 had exceeded its movement authority and was still moving, until the headlights of train 1J25 came into view approximately 13 seconds before the collision (paragraph 61).

280 The signaller's workstation at Machynlleth shows the movement and position of all trains on the line. However, the display only shows which block section a train is occupying and so, once train 1J25 left the loop and entered the single line, the signaller had no visual indication of the precise position of the train once it had passed block marker MH1081.

281 During the GSM-R call made by the driver of 1J25 to the Machynlleth signaller (paragraph 55), the signaller did not gain an accurate awareness of the developing situation or the need to take action to protect other trains. This may have been because the call from the driver of train 1J25 was a normal GSM-R call and not a REC call.

282 The message given to the signaller by the driver of train 1J25 was that they were "sliding through Talerddig and going to pass the block marker, I think". It was not clear to the signaller from this message that the train was unable to stop. The relatively calm tone of the driver of train 1J25 also did not lead the signaller to perceive that there was an impending emergency. This is likely because the driver of train 1J25 believed at that point that the train would stop (see paragraph 375).

283 During that call, an alarm on the signaller's workstation can be heard activating as train 1J25 passed block maker MH1078. At the end of the conversation, the signaller did not anticipate that train 1J25 would move beyond the loop. Consequently, when the signaller called the driver of train 1S71 they stated that "1J25 has just slid past the block marker in the loop and is occupying the points". This meant that the driver of train 1S71 had no reason to believe that train 1J25 was still moving and might pose an immediate risk to them.

284 Had the driver of train 1J25 made a REC call then the driver of train 1S71 would have also heard the call. The driver of train 1S71 would have been required by the Rule Book to stop their train (paragraph 278). The reasons for the driver's use of the GSM-R are discussed at paragraph 375.

285 Rule Book GERT8000 Module G1, 'General safety responsibilities and personal track safety for non-trackworkers', issue 9.1 dated November 2022 which was in force at the time of the accident. This establishes a hierarchy which determines who should lead safety-critical conversations between railway staff. In this case, the signaller was expected to lead the conversation and ensure that a clear mutual understanding of the messages was gained.

286 Although the signaller was up to date with their assessments (paragraph 39), they did not lead the conversation with the driver of train 1J25 and no clear understanding was reached confirming this train's location and continuing movement. If the signaller had gained a clearer understanding of the situation, the risk to train 1S71 presented by the movement of train 1J25 would have been apparent. This may have led the signaller to make a REC call themself or have led them to instruct the driver of train 1S71 to stop before the block marker.

287 The earliest opportunities to have brought train 1S71 to a stand would have been by means of a REC call sent by the driver or the signaller. RAIB analysis shows that bringing train 1S71 to a stand in this manner would not have prevented the collision, as train 1J25 would have continued moving at a relatively constant speed down the descending gradient. However, train 1S71 may have been stationary by the time of the collision rather than moving at 11 km/h (paragraph 61). This would have reduced the overall energy to be dissipated following the collision and may have mitigated the consequences of the accident.

Collision speed: non-operational lineside traction gel applicator

288 **The TGA located on the railway to the west of Talerddig loop was not operational. This is a possible factor affecting the consequences of the accident.**

289 TGAs are items of lineside equipment located at fixed positions where adhesion issues are known to affect a train's ability to accelerate or climb a gradient. A TGA, known as 'Talerddig 1' (figure 52 and appendix E), is located on the railway between the loop at Talerddig and the collision site, within the designated HRLA site (paragraph 252). Talerddig 1 is configured to assist eastbound trains climbing Talerddig bank (as train 1S71 was doing before the accident). It had been installed in response to difficulties experienced by drivers of eastbound trains due to the steep gradient and the exceptionally low adhesion environment in the area. Such issues were being encountered by train 1S71 (paragraph 57).

290 In the case of Talerddig 1, a sensor is located approximately 47 metres to the west of the TGA dispensing head. Thus, an eastbound train will encounter the sensor first and this will cause a pump to apply traction enhancing gel to the railhead from the dispensing head, before the (eastbound) train reaches it. Conversely, a westbound train (such as train 1J25) will encounter the dispensing head before the sensor. As a result, a westbound train will only gain any direct benefit from this TGA if the train is longer than the distance between the sensor and the dispensing head.

291 The distance between the first and last wheelsets of train 1J25 was approximately 45 metres. Consequently, traction gel would not have been deposited until after the last wheelset of train 1J25 had passed the dispensing head. However, train 1J25 could have benefited from residual gel deposited by the passage of preceding trains. The preceding trains were 1I28, the 17:28 Aberystwyth to Birmingham International service, and 1J23, the 16:07 Birmingham International to Aberystwyth service. These trains passed each other at Talerddig loop at approximately 18:29, almost an hour before the accident.

292 In the hours after the accident, the track around the TGA was visually examined and photographed by RAIB. The railhead in the vicinity of the TGA showed no visible signs of traction gel. On 25 October 2024, a subsequent examination by Network Rail staff found the unit to be non-operational due to issues with its battery. This was replaced, restoring the TGA's function.

293 RAIB has been unable to determine the point at which the Talerddig 1 TGA ceased to function. Network Rail standard NR/L3/TRK/3510/C01, 'Use of traction gel applicators', issue 1 dated 03 September 2011, requires that TGAs are inspected every 2 weeks. Records show that Talerddig 1 TGA was last inspected 12 days before the accident on 9 October and was reported as working. When examining Talerddig 1 TGA after the accident, Network Rail staff also examined another TGA, known as 'Talerddig 2', located between the accident site and Machynlleth. The staff observed similar volumes of traction gel in the reservoirs of both devices. Since both were topped up previously at the same time, and Talerddig 2 was still working, Network Rail concluded that Talerddig 1 had likely been working until shortly before the accident.

Figure 52: Non-functioning Talerddig 1 TGA; note the plastic lid under the rail which has collected small sand particles from the traction gel (likely when they are washed off the rail by rain).

294 RAIB sought to understand the possible effect that a functional TGA may have had on this accident. Research[15] indicates that traction gel can spread along the rail for between 40 and 89 metres. However, RAIB was unable to find any reliable data to estimate the improvement in adhesion that a TGA is likely to provide. The effect of environmental conditions on traction gel is also not known, including whether it possible that a light rain shower (such as the one that passed through Talerddig shortly before the accident) can wash off the traction gel, and to what degree.[16]

[15] Investigation into the benefits afforded by traction gel applicators and the traction enhancers, dissertation by Lynne Garner at Liverpool John Moores University in 2011.

[16] In the autumn of 2025 RSSB commissioned research on operational testing of low adhesion mitigation methods. This included railhead treatments as delivered by TGAs. RSSB noted an uplift in adhesion greater than that modelled by RAIB. However, the distance over which that improvement could be demonstrated is not known, nor is the effect of rain or other variables.

295 Because the effectiveness of traction gel is not quantified, RAIB modelled a range of scenarios on the WSPER system. The 'best case' was an adhesion increase of 0.02 (from peak μ = 0.035 to peak μ = 0.055) centred at the location of the TGA and applied over 100 metres, which resulted in an estimated collision speed of 26 km/h instead of the actual collision speed of 39 km/h. The 'worst case' modelled was an adhesion increase of 0.005 (from peak μ = 0.035 to peak μ = 0.04) applied for 50 metres, which resulted in an estimated collision speed of 37 km/h (figure 53).

296 RAIB has, therefore, concluded that no credible scenario exists where a functioning TGA at the location of Talerddig 1 could have prevented the accident. However, there are scenarios where a functioning TGA at this location might have lowered the speed of the collision. Such a speed reduction would have reduced the collision energy.

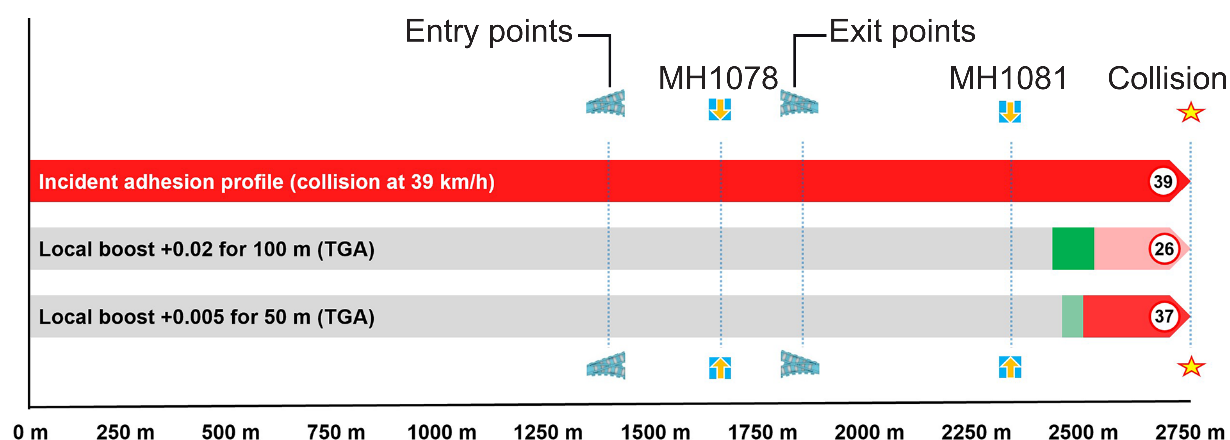

Figure 53: Estimated effect of a range of short local adhesion boosts (centred around the TGA location).

Collision speed: the effects of adhesion modifiers

297 The use of an adhesion modifier delivered by an RHTT may have influenced the overrun, although it is not possible to quantify its influence.

298 Network Rail's RHTT passed over the site 20 hours before the accident. During the passage of the Talerddig loop, the RHTT water jetted part of each side of the loop (paragraph 139). In common with the current policy applied throughout Network Rail's Wales and Borders route, no adhesion modifier was applied by the RHTT.

299 RAIB was unable to find any research or data that could quantify the benefit an adhesion modifier could have achieved, had it been used. A previous RAIB investigation into a low adhesion accident at Stonegate in 2010, RAIB report 18/2011, involved a train which also had automatic sanders that were not working (because the sand hoppers were almost certainly empty). On this occasion the train overran a planned station stop by 2.5 miles (4 km). However, a portion of the track over which it travelled had been treated with an adhesion modifier the night before. On that occasion, train deceleration on the section of line treated with adhesion modifier was approximately 0.5%g (0.05 m/s²) better than on the untreated section, suggesting that the adhesion modifier increased the coefficient of friction by approximately 0.005.

300 RAIB sought to understand the possible effect that an adhesion modifier might have had on this accident. In the absence of any other information supporting the effect of adhesion modifiers, the analysis applied an adhesion boost of approximately 0.005, from peak μ = 0.06 to peak μ = 0.065. This was based on the deceleration improvement experienced by the Stonegate train over the section of track treated with adhesion modifier compared to the track section without adhesion modifier.

301 Assuming that an adhesion boost of 0.005 from a RHTT-delivered adhesion modifier had been available at the time train 1J25 approached Talerddig, RAIB calculated that it would have probably stopped after passing MH1078 but before reaching the exit points of Talerddig loop (figure 54).

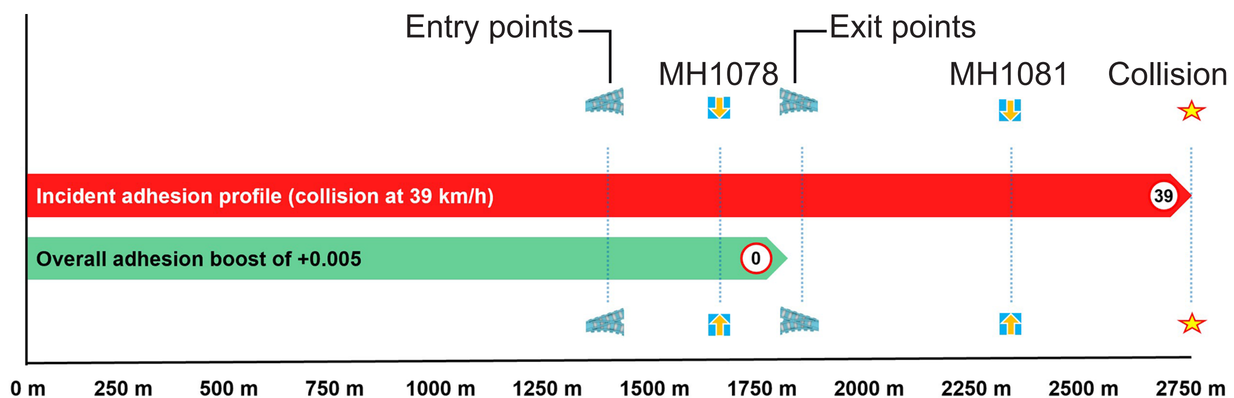

Figure 54: Estimated effect of an adhesion boost of +0.005 through the accident site.

302 However, the expected performance provided by the adhesion modifier currently used on other Network Rail routes is not known. In addition, a 0.005 adhesion increase calculated from events at Stonegate in 2010 represents a single data point, and the following variables are likely to have an effect on the performance of any adhesion modifier that could have been used at Talerddig:

- the effect of between 168 and 200 wheelsets which passed through the site since the RHTT treatment approximately 20 hours before the accident
- the ambient weather conditions during the period between RHTT treatment and the time of the accident, including the effect of wind and rain during this time (paragraph 117)
- the effect of leaf-fall contamination building up on the railhead during the period between RHTT treatment and the time of the accident (paragraph 145)
- the gaps in application of adhesion modifier through parts of Talerddig loop, in line with the methodology for water jetting (paragraph 139)
- the unknown relative performances of the adhesion modifier used at Stonegate and that currently used on other Network Rail routes.

303 An analysis shows that an adhesion increase, over the entire area of low adhesion, of 0.005 may have been enough to avoid the accident. However, there is insufficient evidence to determine if the adhesion modifier which is used by Network Rail on other routes could deliver such a benefit in the circumstances at Talerddig. For this reason, RAIB considers the most likely effect would have been a reduction in the collision speed between the two trains. However, the significant uncertainties in the expected performance mean that the magnitude of the potential reduction in collision speed cannot be precisely quantified. The absence of any research or data regarding the performance of adhesion modifiers is discussed further in paragraph 383.

Injuries to those on board the trains

304 The driver of train 1S71 attempted to vacate the cab immediately before the collision (paragraph 60). However, the movement of the control desk, floor and collision beam during the collision caused the cab door to jam, which trapped the driver in the cab. The driver suffered serious injuries and was released with assistance from a passenger and the driver of train 1J25.

305 One passenger travelling on train 1J25 received fatal injuries as a result of colliding with a saloon table. This passenger was seated in the rear vehicle, 52841 (figure 55). Another passenger in the same vehicle suffered serious facial injuries as a result of their face striking the back of the seat in front of them. This passenger sustained fractures to the jaw and nose and lost a tooth. A third passenger in the same vehicle reported being knocked unconscious for about 20 seconds.

306 The guard in train 1J25 had just left the rear vestibule and was walking along the aisle in the direction of travel when the trains collided. The guard was projected forward and onto the floor. They sustained head trauma, tearing to tendons on both shoulders and a laceration to the right forearm, along with other injuries.

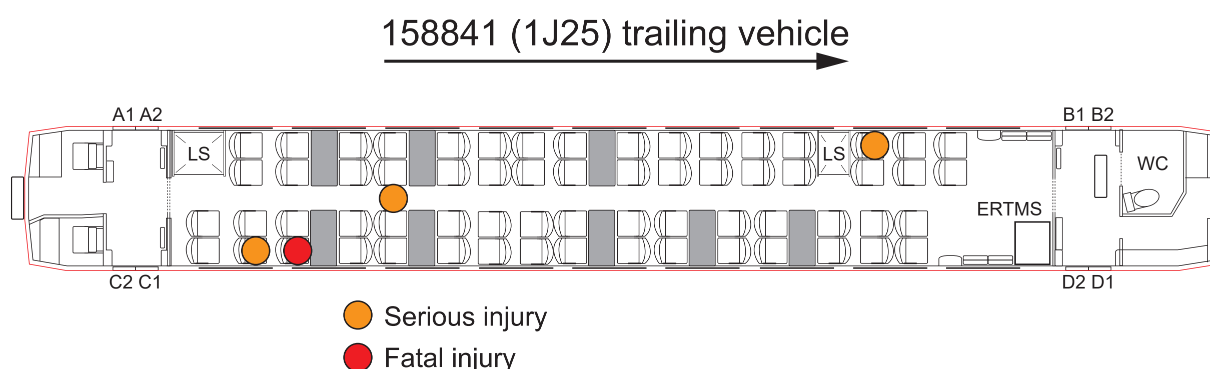

Figure 55: The location of individuals on board vehicle 52841 who sustained serious or fatal injuries.

307 Other passengers on both trains reported minor injuries, including impacts with tables, or the seat in front of them. Some sustained bruising or cuts as a result.

Performance of the vehicle structures

308 There was a loss of cab survival space on train 1S71.

309 The collision between trains 1J25 and 1S71 was on an almost straight but vertically inclined section of track. Although the units involved are identical and so corresponding components on the cab ends would theoretically engage during the collision, there was a small degree of overriding. This meant that the very rigid underframe corner structure of the leading vehicle of train 1J25 (vehicle 57841) engaged slightly higher on the cab end of the leading vehicle of train 1S71 (vehicle 57824). Consequently, the driving cab of vehicle 57824 suffered more damage than that of vehicle 57841, indicating that it absorbed a greater proportion of the collision energy (figures 56 and 57).

Figure 56: Damaged cab ends side-by-side on site (after separation) to show difference.

310 The vertical gangway pillars on vehicle 57824 failed at the welded joints where they join the vehicle structure at floor level. This meant that the cab desks on both sides of this vehicle were pushed towards the rear of the vehicle. The displacement was greater closer to the central gangway than at the outer edges, resulting in a large reduction of the space where the cab seats are located (figure 57). Examination of the surviving parts of the cab structure from this vehicle showed that the gangway pillars, corner pillars and collision beam at cantrail level had all been overloaded and failed at a number of welds.

311 The design of the class 158 cab structure was based on UIC[17] 566 'Loading of coach bodies and their components' which was applicable at the time of construction. UIC 566 defined a range of proof loading requirements to apply to the structure when considering its structural integrity. This included longitudinal loads applied to the cab structure at various heights from floor to cantrail, where the bodyside meets the roof, which had to be sustained without permanent deformation. A review of the corresponding requirements contained in the standard current at the time of the accident, BS EN 12663-1:2010, 'Structural requirements of railway vehicle bodies', issued in 2010, shows that the magnitude of the longitudinal loads applied to the cab structure are the same. This suggests that the proof strength of the cab structure of a modern cab would be similar to the proof strength of a class 158 cab structure.

[17] Union internationale des chemins de fer, an association which promotes international rail transport co-operation.

Figure 57: Cab of vehicle 57824 after the collision, showing loss of survival space.

312 Unlike modern standards, such as BS EN 15227, 'Crashworthiness requirements for rail vehicles', UIC 566 did not define specific collision scenarios to assess the crashworthiness performance of the vehicle in the event of an accident. This standard defines what should happen to the body structure when subjected to loads greater than its proof strength as can occur during collisions. Therefore, the class 158 structure was not designed to meet any specific crashworthiness requirements.

313 Nevertheless, as the class 158 structure was an early application of welded aluminium in UK train construction, a considerable amount of work was undertaken when it was designed to understand its crashworthiness performance. Part of this work included assessing its crashworthiness performance against an emerging internal British Railways Board standard, CP/DDE/116, 'Structural requirements for the bodies of multiple unit vehicles', which contained collision scenarios.

314 A British Rail report published in 1989 concluded that, when assessed against CP/DDE/116 requirements,

> ‘*the class 158 is not a good crashworthy structure: high force levels and low energy absorption at low impact velocities are evident with deceleration levels approximately twice the suggested values*’.

In 1991, the class 158 cab structure was crush tested in a controlled environment. British Rail concluded that ‘*the energy absorbed by the cab ends in the tests was sufficiently high to meet British Rail’s latest standard but the peak forces generated during the test were much higher than in comparable steel vehicles and the mode of deformation rather aggressive*’. RAIB calculated the collision energy produced by the accident at Talerddig and estimated it to be between 200% and 300% greater than the energy absorbed in these tests.

315 RAIB has not made a specific recommendation relating to the crashworthiness of the driver’s cab of the class 158 unit because this has been previously addressed by Angel Trains as part of their response to recommendation 19 (c) of RAIB’s report into the derailment of a train at Carmont, Scotland (RAIB report 02/2022) (see paragraph 426).

The performance of the saloon tables

316 The design of the saloon tables was such that a passenger sustained fatal injuries due to impact with one.

317 Some of the saloon seating in TfWRL class 158 vehicles is arranged so that two pairs of seats face each table. This permits four passengers to sit around the table, two facing forwards, and two rearwards (figure 58). The table comprises a laminated wooden tabletop secured by a rectangular metal bracket that is fixed to the body side of the vehicle below the windows. The aisle end of the table is supported by a vertical tubular support fixed between the tabletop and the vehicle floor.

Figure 58: General arrangement of seating and table in a TfWRL class 158 vehicle.

318 The fatally injured passenger was seated at the rearmost table on the right-hand side of the trailing vehicle of train 1J25 (vehicle 52841, figure 55). The passenger was facing the direction of travel in the seat nearest to the window. The seat opposite was occupied, and the neighbouring seat was unoccupied. At the point of collision, the rapid deceleration involved brought the passenger into hard contact with the table edge. Witness and CCTV evidence is that they were showing signs of having suffered a serious injury immediately after the accident. Post-mortem evidence indicates a clear link between the passenger's death and the injuries sustained from the impact with the table.

319 When examined by RAIB after the accident, the table which the passenger impacted had not detached and remained firmly attached to both the bodyside bracket and support leg. There was, however, evidence that the table was displaced, with measurements taken from the base of the body side bracket showing a small movement of the tabletop consistent with the impact. Other forward-facing passengers also impacted tables during the collision and, as a result, two tabletops in each train were broken from their fixings (figure 59).

Figure 59: A typical detached table.

320 The tables in class 158 vehicles were likely designed to a historic British Rail standard that dates from 1986. This defined structural integrity requirements (proof loads) for the tables of 1000 N vertically and 750 N longitudinally but did not specify any specific crashworthiness characteristics or injury criteria.

321 When the vehicles were new, the tabletops were 20 mm thick. A refurbishment undertaken around 2010 renewed the tabletops and the thickness was increased to 43 mm, but the vehicle bodyside brackets were unchanged. The increased tabletop thickness was expected to reduce the pressure applied to a passenger's abdomen in the event that they were projected forwards into contact with the table edge by the train coming to a sudden stop. This reduced impact pressure was expected to lessen the likelihood of injury causation.

322 The refurbishment in 2010 was not a major change to the interiors so there was no perceived requirement for the table system as a whole to be upgraded to comply with standards that had been introduced following the train's original build.

323 At the time of the 2010 refurbishment, an Association of Train Operators[18] code of practice, AV/ST9001, 'Vehicle Interior Crashworthiness', issue 1 dated February 2002 was in place, although it was not at that time a mandatory standard. As well as defining structural integrity requirements, it also introduced injury criteria. These were values measured and recorded on a dummy that should not be exceeded during a dynamic crash test or simulation (for example, a compression of the abdomen no greater than 40 mm when subjected to an impact defined in the code of practice). The intent of the code of practice was to reduce significantly the extent and severity of injuries from secondary impact, including those with tables. The modification to the table system introduced during the 2010 refurbishment (the combination of tabletop and the associated brackets) was not tested or assessed against AV/ST9001 at the time. However, a judgment was made and recorded by those proposing the change on behalf of the trains' owner and operator that the change afforded '*no increase in overall risk to passengers*'.

324 RAIB has not investigated the 2010 refurbishment and the lack of assessment of the vehicle bodyside table brackets. This is because the process for assessing and (when necessary) certifying the conformance to standards for interior fittings which was then in place is different to current practice.

325 AV/ST9001 was superseded in December 2010 by Railway Group Standard GM/RT2100, 'Requirements for rail vehicle structures', issue 4 dated December 2010. This standard has subsequently been updated, with the current version dated June 2023 being GMRT2100, 'Rail vehicle structures and passive safety' issue 6.2. This standard specified the proof loads as being 1000 N vertically and 750 N horizontally (applied to the edge of the table, in any direction and at any position on the edge) and 1500 N applied horizontally to the outer edge of the table in the direction of the longitudinal axis of the vehicle. GMRT2100 also includes injury criteria, including criteria for chest and abdominal compression.

326 Given the lack of historical assessments, it has not been possible to determine what the effects would have been, had tables compliant to more modern standards been fitted to the TfWRL class 158 vehicles. However, the increase in proof loads for the outer edge of the table suggests that more modern tables would have utilised stronger brackets, which could have had the effect of increasing the forces on the fatally injured passenger's abdomen. Conversely, the requirement to consider injury criteria could also have affected the design in a way that reduced the potential risk of injury.

327 If this work was to be carried out today, in addition to standard GMRT2100, an overarching standard, RIS-2700-RST, 'Verification of conformity of engineering change to rail vehicles', issue 3 dated June 2025, provides information to duty holders about the assessment and verification of changes carried out to railway vehicles.

328 RAIB notes that RIS-2700-RST permits certain minor changes to be carried out to railway vehicles without a full scrutiny and approval being carried out. Appendix B of this document defines such minor changes as:

a. *'Minor modifications;*

b. *Minor repairs;*

[18] Formerly a membership organisation for passenger train operating companies, which merged to form the Rail Delivery Group in 2017.

c. *Direct Replacement Components; and*

d. *Inconsequential changes.'*

It is credible that, unless the principles underpinning RIS-2700-RST were to change, replacing tabletops could be defined as a '*minor modification*' and hence may not be subject to a full review, including the consideration of any changes and improvements to design standards which might have occurred since equipment was originally designed and manufactured.

Seatbelts

329 Class 158 vehicles, in common with all other passenger rail vehicles in the UK and in other countries, are not fitted with seat belts. This means that in end-on collisions, train occupants are vulnerable to secondary impact injuries as a result of being thrown around the vehicle interior. Except for the driver of train 1S71, all the injuries sustained during the accident were assessed as being caused by secondary impact. Seat belts could have been effective in reducing the severity of the secondary impact injuries if they had been fitted and worn by the occupants at the time of the accident.

330 Following the derailment at Ufton Nervet in 2004, the railway-led formal inquiry into the accident recommended that research be undertaken to assess whether there could be a net safety benefit in fitting seat belts on passenger vehicles. The Rail Safety and Standards Board[19] (RSSB) subsequently undertook research on seat belts and concluded that:

> '*Seat belts have the potential to restrain people during accidents, but they can also cause damage to the wearer through their impact on different parts of the body under similar circumstances. More importantly, the analysis of injuries and damage to vehicles showed that, if people were restrained in their seats during an accident, the loss of 'survival space' arising from damage and intrusion to the bodysides of passenger vehicles would be likely to lead to more injuries and fatalities than if people are not so restrained. The seat reinforcement required for fitment would also increase injury potential for occupants who, for whatever reason, were un-belted (that is, they would have something harder to strike against). Accordingly, the use of seat belts in passenger trains was ruled out and the passenger and crew containment strategy was established'*.

331 Following the derailment at Grayrigg (RAIB report 20/2008), RAIB made recommendation 25e to RSSB to review its previous research on seat belts, because passengers had been thrown around the vehicle interior in that accident but there had not been any significant loss of survival space. Therefore, the additional risk of passengers suffering crush injuries because they had been restrained in their seats (noted in the RSSB research as a significant disbenefit of seat belts) did not materialise. ORR subsequently reported to RAIB that the recommendation had been duly considered by RSSB, but no further research work was done. At Talerddig, RAIB observes that there was no loss of survival space in the passenger areas.

[19] The Rail Safety and Standards Board is a not-for-profit company owned by major industry stakeholders. It is the independent safety, standards and research body for Great Britain's rail network.

332 RAIB believes that RSSB's original (post Ufton Nervet) justification for the non-fitment of seat belts for passengers is not supported by the more recent crashworthiness investigations carried out following the accidents at Grayrigg and Talerddig. However, RAIB acknowledges the many practical difficulties associated with seat belt fitment (such as standing passengers) and the likelihood that any cost-benefit evaluation is most unlikely to show that it is reasonably practicable to fit them.

The performance of interior doors

333 **There was a loss of a viable egress route for some passengers due to jammed internal sliding doors and other vehicle damage.**

334 The exterior doors of class 158 vehicles are located at each end of the body. The area adjacent to these doors (the vestibule) is separated from the main saloon area by sliding doors. The purpose of these doors is to improve passenger comfort, by isolating the saloon area from draughts when the exterior doors are open. Each saloon-to-vestibule door has two door leaves. These meet in the middle of the doorway and are power operated so that each leaf opens to its respective side (bi-parting). The vestibule doors are electrically operated, and each leaf moves on runners located above the door aperture.

335 The exterior doors at the front end of vehicle 57824, which was leading train 1S71, were not available for use by passengers as damage to the vehicle body affected their operation. This meant that the only exit from this vehicle was via the rear exterior doors. However, witness evidence indicated that the bi-parting sliding doors at that end were jammed in the runners, which meant the passenger in that vehicle was trapped. Passengers in vehicle 52824 (the trailing vehicle on train 1S71) had to force open these bi-parting doors to allow the trapped passenger to escape and to access the injured driver. Although no injuries occurred because of these doors becoming jammed, the blockage of otherwise viable egress routes is undesirable and may increase stress or cause passengers to injure themselves when seeking alternative routes. All the passengers on the other three vehicles had a viable means of escape.

336 The bi-parting doors on class 158 trains are identical to those fitted to class 159 trains. The performance of these doors on class 159 trains during a collision is described in RAIB's report into a collision between two trains at Salisbury which made a recommendation to mitigate the risk of such doors jamming in the event of an accident (see paragraph 443).

Performance of access panels

337 **Fallen and opened access panels impeded access to the train by the emergency services in the immediate aftermath of the accident.**

338 Like most passenger rolling stock, class 158 vehicles have storage areas and equipment cupboards that are not accessible to passengers. These spaces have panels, often hinged, that are secured to prevent unauthorised access. Similarly, access to the roof space (usually for maintenance) is achieved by opening ceiling panels that are secured using simple catches or locks. Analysis of internal CCTV from train 1J25 identified three instances of interior ceiling or wall panels coming open because of the collision. This resulted in at least two available escape routes becoming partially and temporarily blocked.

339 The rear exterior door on the right-hand side (in the direction of travel) of vehicle 52841 (the trailing vehicle of train 1J25) was used by the emergency services for access. However, a rubbish bin and a panel adjacent to the door were forced open by the collision and were partially blocking their access. Use of a stretcher to remove a casualty from the train was hindered by these panels until railway staff secured them.

340 Another exterior door at the leading end of vehicle 52841 was blocked when a ceiling panel dropped down. The downward movement of this panel was stopped partway by a door control panel located by the exterior door, which had also come open as a result of the collision. The resting position of the ceiling panel may have restricted access to the door emergency release button.

341 In the leading end of vehicle 57841 (the leading vehicle of train 1J25), a control panel came open. This panel carries the passenger door control buttons and the door emergency release button that can be used by passengers. With the panel open, the button was still accessible but the text that describes its function on the panel was not visible. In an emergency, the obscuring of an emergency door control button and the lack of available description of its function may have caused confusion amongst passengers and hindered their egress.

342 GMRT2100 (paragraph 325) requires new trains to have secondary retention fixtures to restrain interior access panels in an accident. This is normally achieved by the fitment of short straps or cords to the panels. These will allow them to be opened enough to detach the strap, and then the panel can be fully opened. Such secondary retention was not fitted to the trains involved in this accident. Compliance with this standard is only required for older rolling stock if changes to the interior would be classed as '*new, renewal or upgrade*'. This would not have been applicable on the TfWRL class 158 units at the time of their refurbishment in 2010 (paragraph 321).

Identification of underlying factors

The operation of trains under ERTMS in low adhesion conditions

343 **There was a longstanding misalignment between the system safety models used for the Cambrian ERTMS signalling system and class 158 rolling stock. This is a possible underlying factor.**

344 The Cambrian lines are equipped with an early deployment installation of ERTMS, a project started by Network Rail and intended to provide information about how future ERTMS projects could be deployed elsewhere on the mainline network. The train operating company incumbent at the time of the installation was a part of the ERTMS implementation which included decisions relating to the management of low adhesion conditions.

345 The documentation used to determine the braking performance and potential for overrun beyond a movement authority for the Cambrian ERTMS scheme assumed a '*normal*' level of wheel-rail adhesion. The Railway Group Standards in force at the time did not define what is considered '*normal*' and referred to '*low adhesion*' conditions as being out of scope of the standard.

346 Assumptions for the braking performance used within the Cambrian ERTMS system are detailed in document ERTMS/CCMS/7884993, 'Braking Using ERTMS for the Cambrian Project', version 5.0 dated 23 September 2010, a document produced by Network Rail. Section 4.1 of this document states that, '*due to the impossibilities of accounting for all adhesion levels without making the system overly conservative in normal operation, very low adhesion levels would require a driver to adapt their driving style to control the speed of the train safely'*. This document also states that the data used to represent class 158 braking performance was taken from Railway Group Standard GM/RT2044, 'Braking System Requirements and Performance for Multiple Units'.

347 Issue 4 of GM/RT2044, dated June 2001, was applicable at the time of the commissioning of the ERTMS project. This states the braking performance defined in the document was applicable to trains operating with 'normal' levels of adhesion available. The definition of normal adhesion used in this standard is derived from Railway Group Standard GM/RT2045, 'Braking Principles for Rail Vehicles'. At the time, GM/RT2045 issue 2, dated April 2000, was applicable. This states that, in conditions of low wheel-rail adhesion, the retardation that can be maintained is reduced and measures to achieve the required stopping distance are necessary. The measures listed to achieve the required stopping distance include a reduction in speed, railhead surface conditioning, or a means of braking that does not rely on the wheel-rail adhesion.

348 The 'Managing low adhesion' manual includes a table for the levels of wheel-rail adhesion which might be experienced on the rail network (paragraph 74, table 1). It can be seen from these definitions that 'low adhesion' relates to a value of μ between 0.05 and 0.09: '*Typical autumn mornings due to dew / dampness often combined with light overnight rust'*. 'Exceptionally low' adhesion would be considered for values of μ less than 0.05 and are described as '*Severe rail contamination often due to leaves but sometimes other pollution*'.

349 Neither GM/RT2044 nor GM/RT2045 define the value of μ which would equate to low adhesion and therefore require railhead conditioning. However, RAIB considers the rail industry guidance definition of low adhesion being a '*typical autumn morning'* with a minimum value of μ of 0.05 to be a normal condition which could be encountered and mitigated with railhead conditioning by sanders. This is supported by the WSPER testing undertaken by RAIB which demonstrates that, with functioning sanders and an average peak value of μ of 0.06, train 1J25 would have mitigated the prevailing railhead conditions and prevented the accident (paragraph 187). Low adhesion conditions below this value are likely to require drivers to also adapt their driving style, as stated in the ERTMS documentation.

350 GI/RT7006 (paragraph 263) states that '*overruns due to low adhesion'* are not within its scope. The guidance note associated with this standard, GI/GN7606 clarifies the reasons for this exclusion as follows:

a. *'It is difficult to predict whether the effects of low adhesion problems will be localised or widespread at any given site. When a train encounters a widespread area of low adhesion, as can be caused by leaf fall, a train may travel a considerable distance before coming to a stand (possibly passing more than one signal). It is not considered reasonable to expect the design of the track and signalling to cater for such eventualities.*

b. *Low adhesion is an effect which is not necessarily present at any given site throughout the service life of the track and signalling. Indeed, in the case of leaf fall, it may well appear in the autumn of one year at a specific location, and disappear the next year.*

c. *There are other measures (eg operational procedures – see GO/RT3356 and GE/RT8040; sanding – see GM/RT2461,[20] lineside vegetation – see GC/RT5202) for dealing with the problem of low adhesion, and these are considered to be the best mechanisms for coping with the problem.'*

351 Neither GI/RT7006 nor GI/GN7606 identify what value for μ characterises a low adhesion condition which would be out of scope for overrun protection. However, RAIB considers it is unlikely that the adhesion levels typically found on Network Rail infrastructure would have been considered to constitute such an out-of-scope condition. It is the *'low levels of adhesion because of leaf fall which results in an overrun possibly exceeding more than one signal section'* which RAIB considers would fall into the rail industry guidance definition of *'exceptionally low adhesion'.*

352 Paragraphs 344 to 351 describe how class 158 units operating on the railway network are vulnerable to overruns in exceptionally low adhesion conditions with a value of μ less than 0.05. These paragraphs also show how it is necessary for class 158 units to rely on sand in the low adhesion conditions associated with a value of μ between 0.05 and 0.09, as can typically be found on the rail network in autumn. Without this rail conditioning, a class 158 unit would not be expected to reliably meet the braking performance criteria detailed in GM/RT2044.

353 Trains on the Cambrian lines are not expected to overrun their movement authority based on the stated maximum allowable rate for an exceedance of the permissible speed or distance. The constant supervision of trains operating under ETCS is responsible for preventing such overruns. The prevention of overruns in accordance with this expectation is important as it forms the base justification for providing short overlaps and not undertaking any detailed overrun risk assessments (paragraph 267).

354 Any train operation is critically dependent on the train's ability to control its speed and stop within the distances adopted by the signalling system design. The train's ability to deliver such control is, in turn, dependent on a sufficient wheel-rail adhesion level.

355 The accident at Talerddig demonstrates that the reduced overlaps and absence of detailed overrun risk assessments, which were permitted when the ETCS signalling system was introduced, meant that the importance of correctly functioning sanding systems was increased for trains operating on the Cambrian lines. RAIB found no evidence that this increased reliance on the integrity of the sanding system in such circumstances was recognised by any of the duty holders directly involved in implementing the ERTMS project, managing the Cambrian lines infrastructure, or operating the trains involved in this accident. An alignment of the system safety models would have recognised the critical contribution that a train's sanding system had to make in ensuring the safe operation of trains in low adhesion conditions. Such recognition would possibly have resulted in enhanced maintenance for the sanders, or a system analysis which could have exposed the potential for dormant electrical failures to inhibit the operation of the sanders with no indication of sander failure provided to train drivers.

[20] Appendix C discusses this and other related standards in more detail.

Assurance of automatic sander operation

356 **TfWRL's processes intended to ensure the operation of the automatic sanding system were not sufficiently effective.**

357 TfWRL carries out the maintenance for its class 158 units (paragraph 29) in accordance with a defined maintenance plan. This maintenance plan includes a number of procedures covering the automatic sanding system.

358 As part of preparing for each autumn, an annual test is conducted to measure the sand delivery rate of each sander. For this test, the maintenance technician places bags over the sand delivery hoses (to catch the sand) and presses the sander test button for 30 seconds (paragraph 161). The test requires that the amount of sand discharged from each sand hose is between 0.75 kg and 1.0 kg in 30 seconds (equivalent to 1.5 kg to 2.0 kg per minute). For unit 158841 (which formed train 1J25), the test was recorded as having been completed on 25 September 2024, 26 days before the accident. Although the maintenance procedure requires that the actual weight of sand discharged is recorded, there was no facility to do so within the maintenance planning system used by TfWRL. Consequently, the records show only that the task was completed, and do not record the amount of sand discharged (appendix C, paragraphs C7 and C8).

359 The last routine maintenance test which could have identified either of the electrical faults within the automatic sander system (paragraph 167) was completed on 12 October, 9 days before the accident. This was part of a 'wheel slide protection system test', which is included as part of a routine maintenance inspection known as a B exam. This is undertaken approximately every 7,500 miles (12,000 km). This test was recorded as successfully completed and did not record any electrical faults in the system. Given the intermittent nature of the defect with the LSR4 relay (paragraph 163), it is possible that the fault was present at this time but did not manifest itself during the testing.

360 A basic check of the sanding system was carried out on Sunday 20 October, the day before the accident, as part of a fuel point examination (paragraph 33). This test was recorded as successfully completed, which suggests that the sand hoses were not blocked at this time. However, the testing process used could not have identified either of the dormant electrical faults. This is because the test methodology, which used the sander test button on the hopper, derives an electrical supply from a separate circuit which is not supplied from the sander isolation switch. The sander test button circuit also bypasses the low-speed relay (paragraph 161).

361 Before the accident, testing the operation of the automatic sander was reliant on the use of the sander test button and periodical depot examinations. However, because the sand test button circuit would not reveal an electrical defect such as those found on unit 57841, the automatic sanders could remain inoperable until the next depot examination, a period of up to a fortnight. The frequent use of the sand test button could give a false impression that the automatic sanding system was fully operational. The potential for an unrevealed fault to exist for a period of up to a fortnight was not understood by TfWRL before the accident, and their processes were not sufficiently effective in ensuring that the automatic sanders on train 1J25 would work when required.

TfWRL's understanding of the ERTMS system

362 **TfWRL had an incomplete understanding of the ERTMS system and its drivers' interactions with it. This is a probable underlying factor.**

363 As well as reducing the maintenance burden associated with lineside signals and indicators, ERTMS allows drivers to delay their braking until closer to the end of the movement authority, compared to conventional signalling. This is because the DMI provides continuous information on the appropriate speed along the route ahead (as opposed to the periodic updates provided by lineside signs and signals). The supervision system also gives protection against driver error by applying the brakes if the target braking profile is not met. This, in turn, allows more trains to run on a given route.

364 The DMI guides the driver towards this target braking profile. ETCS calculates this profile to stop the train close to, but not exceeding, the end of movement authority, or to slow it appropriately by the point of the start of a reduction in permissible speed. The calculation of this braking profile does not assume the maximum available braking performance of the train. This provides a margin so that, if required, an SBI can control the train without there being an overrun or overspeed.

365 The nature of in-cab signalling systems, such as ETCS, means that to fully exploit the advantages of in-cab signalling, while avoiding SBIs, drivers will focus on the DMI and keep close to the speed indications it provides. This contrasts with conventionally signalled lines where drivers must use their route knowledge and the information provided by signs and signals to plan ahead and control their speed appropriately. This change in emphasis may mean that drivers operating with in-cab signalling systems are less aware of upcoming changes, such as being routed into a loop, where the diverging route has a lower line speed. This is supported by a survey which RAIB undertook of drivers on the Cambrian lines who reported that they felt too little information was provided by the DMI about the route their train would take at stations, junctions and passing loops. Academic research suggests that more information provided in the planning area could assist drivers in developing more effective driving strategies.[21]

[21] Young MS, Stanton NA and Walker GH, 'In loco intellegentia: human factors for the future European train driver', International Journal of Industrial and Systems Engineering, 1 (4), 485-501 (2006).

366 RAIB also found there was confusion over the different warning colours attached to the speed hook, with some drivers unaware of the existence of the orange colour. This indicates a lack of complete knowledge of the system by some drivers. In addition, research[22] suggests there is little or no difference in the connotation of these colours, given that white, yellow or orange can signify a warning (paragraph 215). A lack of discriminability between these similar colours could also potentially create confusion. Research also shows that if the system is not transparent or explicit, drivers may find it difficult to form a complete, accurate and effective mental model to support them in the driving task. Principles of good display design[23] also include the importance of minimising perceptual confusion and the need to make the discrimination of modes as visible as possible by employing salient and visual cues. This lack of understanding of the different colours of the speed hook highlights the importance of effective training to ensure drivers fully understand system-generated warnings. However, TfWRL lacked the detailed knowledge of the operation of the ETCS system to be able to provide the necessary information, to the required depth, to drivers.

367 In addition to the OTDR, ERTMS-equipped trains are fitted with an additional data recorder known as a JRU (paragraph 32). This is independent of the OTDR and records signalling and journey parameters directly from the ERTMS system. This additional data provides information on ETCS activity such as an SBI.

368 During the investigation, RAIB found that TfWRL was not aware of how frequently SBIs were occurring. However, RAIB was provided with witness evidence from drivers that they could experience an SBI as frequently as once a week. This is supported by data taken from the JRU on board unit 158824 which indicates that 17 SBIs had occurred in the 21 days preceding the accident on that unit alone.

369 TfWRL did not have full access to the data from the JRUs because it did not have the software required to analyse recorded events. This meant that any requests for usable JRU data had to be made via Network Rail, which TfWRL reported introduced a delay. This, in turn, meant that TfWRL did not request JRU data after minor incidents or for routine analysis of drivers' performance.

370 Because TfWRL did not have full access to the JRU data, analysis of driver behaviour was undertaken primarily using OTDR data. Witness evidence is that, in the absence of full JRU data, TfWRL driver managers had to resort to looking for patterns of brake use within the OTDR data, such as a train going straight to brake step 3 rather than using intermediate steps, that implied an ETCS intervention. The limited data available to TfWRL driver managers meant that the actual number of SBIs identified from that available data was significantly less than the number of such events identified by RAIB from analysis of JRU data.

[22] Wogalter M and others, 'Use of colour in warnings from part V - colour symbolism and association' published online by CUP 2016.

[23] Wickens Christopher D, 'Engineering psychology and human performance', second edition, HarperCollins (1992).

371 If TfWRL had had better access to JRU data, it would have understood that drivers were experiencing ETCS interventions more often than originally believed. This might have prompted TfWRL to examine why these interventions were occurring and to reveal the issue of drivers not always receiving the early warnings of subsequent lower line speeds because of the potential masking effect of previous warnings (paragraph 226). This in turn would then have been used to ensure that drivers were briefed and trained on this issue.

372 An understanding of the masking effect should have also led to discussions with Network Rail on the justification for closely spaced speed restrictions such as existed on the westbound approach to Talerddig loop.

The training of TfWRL drivers in dealing with abnormal events

373 **TfWRL's training and competency management did not effectively prepare the driver of train 1J25 to take the correct actions on realising that the train would exceed its movement authority. This is a possible underlying factor.**

374 TfWRL's train driver competency standards handbook, version 1a, dated June 2019, describes the areas of driver competence that are assessed. Competency assessments are carried out at set points throughout the span of a driver's competency cycle. The driver of train 1J25 was up to date with their competency assessments at the time of the accident. Before the accident they had also recently undertaken a 'summary day' where they were tested on any areas not already assessed within their current cycle, as well as on other topics.

375 The competency cycle for the driver included assessments on the use of GSM-R. On the night of the accident, the driver of train 1J25 used a routine GSM-R call to alert the signaller that they were having difficulty controlling the speed of the train (paragraph 55). The call to the signaller commenced before train 1J25 had passed block marker MH1078. Despite detecting that the train was not slowing as they would expect, the driver was anticipating the level of adhesion would improve and so did not initially perceive the situation to be an emergency and this may have influenced their decision not to make a REC call at this point. The rules relating to making REC calls are discussed in paragraph 278 and the possible effect of not using this facility to make an emergency call during the accident is described at paragraph 284.

376 TfWRL's competency standards handbook also deals with how drivers respond to '*out of course*' situations. While the emergency sanding system is not explicitly mentioned, there is a section within this covering '*operating a train safely in adverse and severe weather conditions and exceptional railhead conditions*'. TfWRL's assessment of drivers' knowledge of class 158 units (the only TfWRL units fitted with an emergency sanding system) also contains specific questions on understanding the status of the emergency sanding systems and when and how to use it.

377 After the driver became aware that they were going to exceed their movement authority, they did not use the emergency sanding system (paragraph 193) as was required by the Rule Book (paragraph 202).

378 Although the driver was aware the train was fitted with an emergency sanding system (paragraph 203), they stated that it had not occurred to them to use it on the night of the accident. The train driver's initial belief that the train's speed would reduce without further intervention may explain why they did not use the system (paragraph 206). It may also be explained by their change in attentional focus after they made the decision to call the signaller (paragraph 208).

379 Although TfWRL stated that the driver would have been trained in the use of the emergency sanding system, the driver had not used the system before and had no recollection of having been trained in its use (paragraph 205). A survey of TfWRL drivers undertaken by RAIB after the accident sought to understand how well drivers understood TfWRL's class 158 braking instructions (paragraph 203) relating to the use of the emergency sanding system. The results of this survey revealed a lack of clarity by drivers about the circumstances that required its use.

380 While the driver's precise levels of stress at various times leading up to the collision are not known, they are likely to have varied. Human performance can be affected by stressful situations. This is because stress can affect different areas of cognitive function such as memory, judgment and decision-making. This can lead to people having difficulty following procedures in a correct, timely or accurate way. Stress may also cause attentional narrowing where people pay more attention to positive information and discount negative information. Practice and training of skills and strategies can help to improve the chance of procedures being recalled in adverse and stressful conditions.

381 Another factor that may affect the likelihood of recalling a task action (such as using the emergency sanders) is how frequently a task is undertaken; it is more difficult to remember information that is infrequently used. Research notes that to counteract issues retrieving information in such situations it is important to '*encourage regular use of the information to increase frequency and recency*'.[24] This further supports that using emergency equipment during training will make it more likely that it will be used when required operationally.

382 When the ERTMS system was initially implemented on the Cambrian lines, a class 158 cab simulator was provided by Network Rail to facilitate driver training. This simulator fell into disuse and was subsequently decommissioned. The loss of this simulator removed a potential tool which could maintain driver skills and knowledge when faced with out-of-course and emergency situations such as those encountered by the driver of train 1J25 approaching Talerddig. The simulator may also have been useful to refresh drivers on the masking effect which may affect warnings on the DMI (paragraph 226) had this issue been fully understood by TfWRL.

[24] Wickens Christopher D, 'Engineering psychology and human performance', second edition, HarperCollins (1992).

Network Rail's understanding of adhesion modifiers

383 **Network Rail did not have a detailed understanding of the effectiveness of wheel-rail adhesion modifiers. This is a possible underlying factor.**

384 The joint seasons plan (paragraph 134 and appendix E) defines the routes treated by the RHTT (paragraph 44) and the locations of TGAs (paragraph 289). The plan states that the RHTT would not deposit an adhesion modifier on the Cambrian lines. While there was evidence that adhesion modifiers had been used in the past, the policy within the Wales and Borders route at the time of the accident was that adhesion modifiers were not to be used. Witness evidence indicates that this decision was based on a lack of confidence by Network Rail staff of the benefit that adhesion modifiers provide. Staff also expressed a concern that adhesion modifiers may bring a risk of leaves sticking to a recently cleaned (water jetted) railhead and so have an adverse effect on adhesion.

385 To understand if this view was commonly held, RAIB spoke to seasonal delivery staff working in other Network Rail routes. This revealed that the non-use of adhesion modifiers was considered by seasonal delivery staff in the context of performance as well as safety, and that staff on other routes had also either stopped using RHTTs to deposit adhesion modifiers or were seeking to better understand the effect of not using it. Network Rail staff reported that some routes had stopped using adhesion modifiers without apparent detriment. A Network Rail review, conducted after the 2024 autumn season, showed that 65% of the routes covered by RHTTs had adhesion modifier deposited in addition to water jetting.

386 A common theme reported by seasonal delivery staff was a lack of clear guidance on the effectiveness of adhesion modifiers. Although most seasonal delivery staff reported good formal and informal means of getting advice and support, several reported a lack of knowledge about the performance of adhesion modifiers. One person stated that they believed that the decision not to use adhesion modifiers was sometimes based on a feeling within a route or the opinion of influential staff.

387 RAIB found that there was a similar absence of knowledge across the industry on the effectiveness of TGAs. Although RAIB found research which had tried to understand how far gel deposited by TGAs might spread, the effect of other factors was not well understood (paragraph 294).

Observations

Network Rail's seasonal delivery staff

388 **Network Rail's seasonal delivery team for the Wales and Borders route was operating with reduced resources and the seasonal delivery manager role had no formal competency framework.**

389 Network Rail's aspiration was that the SDM (paragraph 20 and appendix E) would have had three staff reporting to them. At the time of the accident, there were no other seasonal delivery staff in post, although one position had been filled until 10 days before the accident by a person on a 6-month secondment. They took over from a previous post holder who had been in post for a year.

390 Evidence obtained by RAIB indicated that, although the absence of staff resources had meant there was reduced capacity to explore new developments, the overall approach to seasonal management was compliant with Network Rail standards. RAIB found no evidence that these resourcing issues created the conditions for the Talerddig accident to occur, or of any concerns being identified by other rail industry parties working within the Wales and Borders route regarding Network Rail's preparedness for the 2024 autumn leaf fall season. The resourcing of the Wales and Borders route seasonal delivery team is therefore not regarded as being a factor in the accident.

391 Nationally, there was no role profile for SDMs to work to, nor was there a specification for the skills, knowledge and experience needed by the post holder. The issue has been previously identified by RAIB during the investigation into the accident at Salisbury Tunnel Junction in 2021 (see paragraph 437). However, in the case of the Wales and Borders route, the SDM was regarded by both colleagues and others across the industry as being knowledgeable and effective. This lack of framework for the SDM role is also therefore not regarded as being a factor in the accident.

Training of TfWRL staff to deal with emergencies

392 **Some members of TfWRL staff had received no training on the emergency equipment provided on their trains.**

393 In the immediate aftermath of the accident, of the five members of TfWRL staff who were on the trains:

- the driver of train 1S71 was seriously injured
- the guard of train 1J25 was seriously injured
- the driver of train 1J25 was involved in protecting the scene of the accident as required by the Rule Book.

394 This left the guard of train 1S71 and the host of train 1J25 to deal with their respective trains. The collision had taken place in a rural part of mid-Wales, and there was no certainty as to when any external assistance would be forthcoming.

395 Since they are not regarded as safety-critical staff, the host of train 1J25 had not received any form of training to cover actions which could be required in the event of an emergency. In common with others in this post, the host of train 1J25 had not been provided with any information as to how to evacuate a train or the location of emergency equipment such as first aid kits.

396 Although medical evidence indicates that no intervention could have prevented the death of the passenger who was fatally injured, and the guard of train 1S71 rapidly provided assistance to the host, there are a number of credible scenarios where the absence of emergency training for hosts could contribute to a worse outcome.

Other defects in the sanding systems

397 Low sand delivery rates can reduce the potential benefits provided by trainborne sanding systems.

Incorrect pneumatic assembly and partially constricted sand delivery hose

398 In addition to the electrical defects identified within the automatic sanding system on vehicle 57841, several further defects were identified. These defects are not considered to be factors in this accident (paragraph 154). However, these defects could have had an effect on the effectiveness of the automatic sanding system in other circumstances. These defects are described in appendix C and summarised below.

399 The sanding system uses compressed air to move sand from the hopper and to eject it towards the wheel-rail interface. When sand is required, the sander control circuit opens a solenoid valve which allows air to flow from the train air system into the sanding system. The air supply is controlled by orifice plates which are located inside the sand valves. The orifice plates were found to be installed incorrectly on vehicle 57841 (the leading vehicle of train 1J25). Both orifice plates were upside down and one was incorrectly aligned. Physical evidence indicates that the orifice plate had been in this orientation for an extended period. The incorrect pneumatic assembly, and the consequential abnormal wear of the sand valve, is likely to result in a reduced sand delivery rate.

400 Sand delivery hoses direct sand from the hoppers to the point of injection at the wheel-rail interface. The hoses on each side are different lengths by design. On vehicle 57841, they were approximately 2.3 metres long on the driver's side and 1.4 metres long on the non-driver's side. RAIB inspected the sand delivery hoses on vehicle 57841 after the accident and found that worm-drive style hose clamps had been installed on either side of the pipe clip to secure the hoses in position. This is contrary to the design intent of bonding the sand delivery hoses into the pipe clips. One of these hose clamps (on the driver's side) was deformed, resulting in the sand hose being partially constricted approximately 200 mm from the delivery end of the hose. This partial hose constriction is likely to result in a reduced sand delivery rate.

The effect of the incorrect pneumatic assembly and partially constricted sand delivery hose on the accident

401 RAIB conducted testing to estimate the combined effect of the incorrect pneumatic assembly, the partially obstructed hose and the effect of the different sand hose lengths. This testing was intended to replicate, as closely as practicable, the condition of the sanding system at the time of the accident.[25]

402 The testing showed that the driver's side delivery hose (with the longer hose and the partial obstruction) delivered 0.32 kg/minute, and the non-driver's side (with the shorter hose but no obstruction) delivered 1.12 kg/minute. The average value across the wheelset was 0.72 kg/minute.

[25] RAIB had disassembled, inspected, and reassembled the sanding system components in the period between the accident and the testing, and an additional hose coupler was installed to connect to the restricted sand hose (because the incident sand hose was cut off near its end to estimate the depth of the hose blockage).

403 Simulations were undertaken, using WSPER, to estimate the effect of the reduced sanding rate which would result from the incorrect pneumatic assembly and partially constricted sand delivery hose. The WSPER system has not been validated for low sand delivery rates and the 0.72 kg/minute sand delivery rate is significantly lower than the minimum sand delivery rate that was available in the WSPER data library. To estimate the potential effect of low sand delivery rates, some modifications were made to WSPER sand models. These modifications were made based on professional opinion and have not been validated but are considered sufficient for the purposes of this observation.

404 These simulations showed that, with a functional automatic sanding system discharging sand at the lower rate of 0.72 kg/minute, the train would probably have stopped shortly before the exit points of Talerddig loop (figure 60). For this reason, RAIB concluded that, had the automatic sander been working, the accident would still have been avoided even with the low sand delivery rate arising from the other defects.

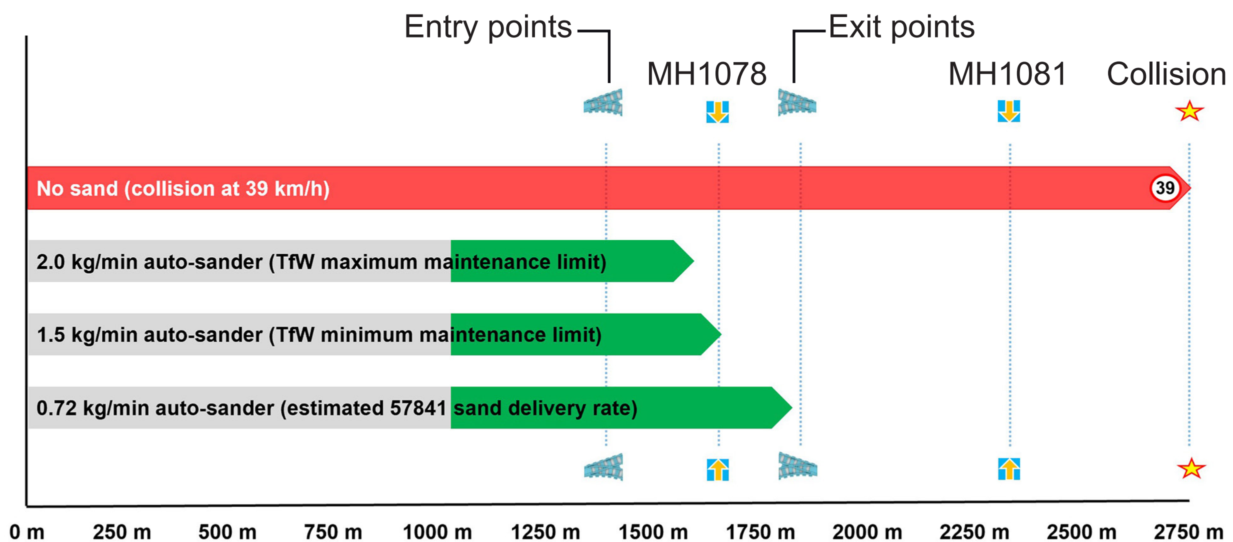

Figure 60: Estimated effect of a functioning automatic sanding system with a reduced sand delivery rate (0.72 kg/min). Higher sand delivery rates (paragraph 184) shown for comparison.

405 RAIB also considered if the deformed hose clamp found on vehicle 57841 reduced the ability of a sanding system to expel blockages from the sand delivery hoses (paragraph 176). Testing showed that a sanding system could still clear a blockage even with a constricted sand hose. Further information on this testing is in appendix C.

The actions of the safety authority

406 ORR is the safety authority and health and safety regulator for railways and tramways in Great Britain. ORR has undertaken this role since His Majesty’s Railway Inspectorate was transferred from the Health and Safety Executive to ORR in 2006.

407 Health and safety legislation such as the Railways and Other Guided Transport Systems (Safety) Regulations 2006 (ROGS) requires railway companies to ensure they assess and control risks that arise from their operations so far as is reasonably practicable. Under ROGS, transport undertakings such as infrastructure managers and train operators must actively co-operate with each other to ensure the safety of the railway system. ROGS also requires that transport undertakings have the necessary safety authorisations and certifications before they can operate vehicles or manage infrastructure.

408 In specific circumstances ORR will authorise and accept new infrastructure and trains. ORR stated that their understanding is that the introduction of ERTMS onto the Cambrian lines was subject to authorisation in accordance with the Railways (Interoperability) Regulations 2006 and accepted in accordance with ROGS. As part of this process, ORR engaged with Network Rail and the train operator then responsible for services on the Cambrian lines from at least 2008.

409 The Department for Transport (DfT) is the authority responsible for determining whether an upgraded or renewed system, or sub-system, requires an interoperability authorisation from ORR against the relevant standards and requirements. In 2011, DfT wrote to the ERTMS programme in response to a request for a determination under the 2006 interoperability regulations as to which aspects of the Cambrian ERTMS project (described as an upgrade) required authorisation. In this letter, DfT noted that the fitment of ERTMS on the Cambrian lines was intended to act as a '*pilot project specifically designed to clarify areas of difficulty both in the actual specification and in the application…*[which] *will inform future national roll out of ERTMS'* and that it did '*not completely represent the design solutions that will be adopted nationally*.'

410 DfT confirmed in this letter that the Cambrian ERTMS project would not be required to apply the requirements relating to the display of a 'Poor adhesion' icon on the DMI. The letter stated that this was '*a presentational difference only. Use NNTR* [Notified National Technical Rules] *to reassess'* and that Arriva Trains Wales and Network Rail had alternative arrangements in place to handle low adhesion. The letter also confirmed that the Cambrian ERTMS system would not be required to comply with the requirement to transmit data providing a change in the adhesion factor used in the system's brake model. The letter stated that this '*Function is not required.*'

411 Documents reviewed by RAIB, corroborated by evidence from witnesses, support the conclusion that ORR was seeking assurance that the operation of trains in low adhesion conditions had been properly considered well before ERTMS-equipped trains were put into service. These documents also show evidence that ORR raised concerns about the masking of indications of consecutive lower speed restrictions ahead of trains (paragraph 240). ORR was told that commissioning trials would better inform the understanding of low adhesion issues and that an ERTMS upgrade in 2012 would resolve the masking issues.

412 Although ORR supplied RAIB with a significant quantity of documentation about its certification of the Cambrian lines ERTMS project, most of the relevant documents from the period from 2012 to 2022 were missing. ORR explained that this was due to an issue with a computer-based storage system in 2017 which had resulted in the loss of many documents. From the remaining documents, it was not apparent how any concerns about the specific issues raised were resolved. Additionally, no references were found to any considerations of the reliability or performance of the automatic sanding systems fitted to ERTMS-equipped class 158 units.

413 ORR's role includes the monitoring of health and safety performance, carrying out inspections and taking action to enforce compliance with health and safety law. ORR plans its routine work on the basis of risk and its analysis of where it can secure the most significant improvements in safety. Its inspections and assessments aim to draw systemic conclusions which will promote improved safety arrangements across a wide range of activities, rather than identifying specific shortcomings.

414 In 2023/24, ORR undertook a planned 3-yearly inspection of TfWRL focusing on signals passed at danger (SPAD) and driver management. The inspection examined areas including fallen trees, excess foliage obscuring signals and warning boards, and the impact of weather on driving conditions, including visibility and wheel-rail adhesion. The inspection also examined how TfWRL's drivers are trained to use GSM-R equipment, to react to low adhesion conditions (including assessing braking points), the different braking characteristics of different units, WSP functionality, and the use of sanders.

415 During the inspection of TfWRL, ORR used its risk management maturity model (RM3[26]) to assess TfWRL's arrangements in three areas. These were internal communications, system safety and interface, and competence management. RM3 assesses the maturity of an organisation's arrangements with one of five ratings, ranging from '*ad-hoc*' (the lowest) (1) to '*excellence*' (5).

416 ORR scored the three areas as either '*standardised*' (3) or '*predictable*' (4). ORR also observed that TfWRL should consider introducing development days and standardisation activities for driving instructors to continually develop individual assessment styles, and to promote a standardised approach across TfWRL. The inspection did not identify any concerns of significance within the scope of the areas covered.

[26] https://www.orr.gov.uk/guidance-compliance/rail/health-safety/strategy/rm3.

Summary of conclusions

Immediate cause

417 Train 1J25 passed its authorised stopping position and entered a single line occupied by approaching train 1S71 (paragraph 96).

Causal factors

418 The causal factors were:

a. Train 1J25 was unable to stop at block marker MH1078 and therefore exceeded its movement authority. This causal factor arose due to a combination of the following:

   i. The available wheel-rail adhesion was unable to support the level of demanded braking without sand being discharged by train 1J25 (paragraph 103), **Recommendation 7**.

   ii. Trainborne systems did not mitigate the prevailing low wheel-rail adhesion because the automatic sander was not working and the driver did not use the emergency sander (paragraph 147), **Recommendations 2 and 6**.

   iii. The approach speed of train 1J25 towards the eastern entry to Talerddig loop was such that the subsequently required deceleration could not be sustained with the available wheel-rail adhesion (paragraph 209), **Recommendation 5**.

b. Having passed block marker MH1078, train 1J25 entered the occupied single line. This causal factor arose due to a combination of the following:

   i. The wheel-rail adhesion beyond block marker MH1078 was exceptionally low (paragraph 247), **Recommendation 7**.

   ii. No engineered mitigations existed to prevent train 1J25 entering the occupied single line (paragraph 257), **Recommendations 3 and 4**.

Factors affecting the severity of consequences

419 Factors that affected the severity of consequences of the event were as follows:

a. Train 1S71 was permitted to proceed to the end of its issued movement authority (paragraph 273), **Recommendation 6, Learning point 1**.

b. The traction gel applicator located on the railway to the west of Talerddig loop was not operational (paragraph 288). This is a possible factor affecting the severity of consequences, **Recommendation 7**.

c. The use of an adhesion modifier delivered by an RHTT may have influenced the overrun, although it is not possible to quantify its influence (paragraph 297), **Recommendation 7**.

d. There was a loss of cab survival space on train 1S71 (paragraph 308), **Recommendation 8**.

e. The design of the saloon tables was such that a passenger sustained fatal injuries due to impact with one (paragraph 316) **Recommendation 8**.

f. There was a loss of a viable egress route for some passengers due to jammed internal sliding doors and other vehicle damage (paragraph 333), **Recommendation 8**.

g. Fallen and opened access panels impeded access to the train by emergency services in the immediate aftermath of the accident (paragraph 337), **Recommendation 8**.

Underlying factors

420 The underlying factors were:

a. There was a longstanding misalignment between the system safety models for the Cambrian ERTMS signalling system and class 158 rolling stock. This is a possible underlying factor (paragraph 343), **Recommendations 3, 4 and 5**.

b. TfWRL's processes intended to ensure the operation of the automatic sanding system were not sufficiently effective (paragraph 356), **Recommendations 1 and 2**.

c. TfWRL had an incomplete understanding of the ERTMS system and its driver's interactions with it. This is a probable underlying factor (paragraph 362), **Recommendation 5**.

d. TfWRL's training and competence management did not effectively prepare the driver of train 1J25 to take the correct actions on realising that their train would exceed its movement authority. This is a possible underlying factor (paragraph 373), **Recommendation 6**.

e. Network Rail did not have a detailed understanding of the effectiveness of wheel-rail adhesion modifiers. This is a possible underlying factor (paragraph 383), **Recommendation 7**.

Observations

421 Although not linked to the accident on 21 October 2024, RAIB observes that:

a. Network Rail's seasonal delivery team for the Wales and Borders route was operating with reduced resources, and the seasonal delivery manager role had no formal competency framework (paragraph 388). This matter is similar to that identified during RAIB's investigation into the accident at Salisbury (see paragraph 436). Recommendation 2 from that investigation (see paragraph 437) remains open at the time of this report. For that reason, no further recommendation is made.

b. Some members of TfWRL staff had received no training on the emergency equipment provided on their trains (paragraph 392), **Recommendation 9**.

c. Low sand delivery rates can reduce the potential benefits provided by trainborne sanding systems (paragraph 397), **Recommendations 1 and 2**.

Previous RAIB recommendations relevant to this investigation

422 The following recommendations, which were made by RAIB as a result of its previous investigations, have relevance to this investigation.

Previous recommendations that had the potential to address one or more factors identified in this report

Investigation into autumn adhesion incidents, RAIB report 25/2006

423 On 8 January 2007, RAIB published a report with three sections into adhesion-related incidents. The three sections covered:

- signals passed at danger at Esher on 25 November 2005
- a signal passed at danger at Lewes on 30 November 2005
- a review of adhesion-related incidents during the autumn of 2005.

424 Recommendation 19 from part 3 of this report reads as follows:

Network Rail to review ERTMS low adhesion assumptions in the light of the findings of this report and consider whether any changes are needed to ERTMS design or operating parameters in the light of the review.

425 In 2014, ORR reported to RAIB that the recommendation had been implemented. However, RAIB noted that the ERTMS programme was still developing requirements and the anticipated Railway Group Standard designed to cover braking performance for ERTMS-fitted vehicles had yet to be issued.

Derailment of a passenger train at Carmont, Aberdeenshire, 12 August 2020, RAIB report 02/2022

426 At around 09:37 on Wednesday 12 August 2020, a passenger train collided with debris washed from a drain onto the track near Carmont, Aberdeenshire, following very heavy rainfall. The train, reporting number 1T08, was the 06:38 service from Aberdeen to Glasgow, which was returning towards Aberdeen due to a blockage that had been reported on the line ahead.

427 The report into this accident was published on 10 March 2022. RAIB made 20 recommendations for the improvement of railway safety. These recommendations covered how the railway manages extreme weather events, management of civil engineering construction activities, management assurance of railway control functions, train design, and applying learning from previous events. Recommendation 19(c), was relevant to the accident at Talerddig and reads as follows:

The intent of this recommendation is to evaluate the additional risk to train occupants associated with the continued operation of HSTs, which entered service before modern crashworthiness standards were introduced in July 1994. This will enable the future planning of HST deployment to be informed by a fuller understanding of any additional risk and the costs and safety benefits of any potential mitigation measures. This learning should also inform thinking about the mitigation of similar risks associated with the operation of other types of main line rolling stock.

Operators of HSTs, in consultation with train owners, ORR, DfT, devolved nations' transport agencies and RSSB should do the following:

a. *Assess the additional risk to train occupants associated with the lack of certain modern crashworthiness features compared to trains compliant with Railway Group Standard GM/RT2100 issue 1 (July 1994), also taking account of age-related factors affecting condition (such as corrosion). This assessment should include a review of previous crashworthiness research (including driver safety), a review of previous accidents, consideration of future train accident risk, the findings presented in this report and any relevant engineering assessments.*

b. *Based on the outcome of a) and cost benefit analysis, identify reasonably practicable measures to control any identified areas of additional risk for HSTs, and develop a risk-based methodology for determining whether, and if so when, HSTs should be modified, redeployed or withdrawn from service.*

c. *In consultation with operators of other pre-1994 passenger rolling stock, develop and issue formalised industry guidance for assessing and mitigating the risk associated with the continued operation of HSTs and other types of main line passenger rolling stock designed before the introduction of modern crashworthiness standards in 1994.*

428 In February 2026, ORR reported that, in response to recommendation 19(c), the owners of class 158 vehicles (Angel Trains, Porterbrook, and Eversholt Rail (now Beacon Rail)) had commissioned an assessment which showed that the class 158 vehicle structure was not fully compliant with GM/RT2100 issue 1 regarding energy absorption, such as in a collision. The vehicle owners, therefore, had carried out a cost-benefit assessment of any possible modifications which could be carried out to achieve such compliance. This assessment concluded that the cost of the modifications needed to achieve compliance with the standard would be grossly disproportionate to any safety benefits achieved.

429 ORR considered on this basis that the recommendation had been considered and action taken to close it.

Collision between passenger trains at Salisbury Tunnel Junction, Wiltshire, 31 October 2021, RAIB report 12/2023

430 On 31 October 2021, two passenger trains collided at Salisbury Tunnel Junction. The causes of the accident were that wheel-rail adhesion was very low in the area where the driver of train 1L53 applied the train's brakes; that the driver did not apply the train's brakes sufficiently early on approach to the signal protecting the junction to avoid running on to it, given the prevailing low level of adhesion; and that the braking systems of train 1L53 were unable to mitigate the very low adhesion which was present. The level of wheel-rail adhesion was very low due to leaf contamination on the railhead and had been made worse by a band of drizzle that occurred immediately before the passage of train 1L53.

431 The leaf contamination had resulted from the weather conditions on the day of the accident, coupled with an increased density of vegetation in the area which had not been effectively managed by Network Rail's Wessex route. Network Rail's Wessex route had also not effectively managed the contamination on the railhead with either proactive or reactive measures.

432 The report into this accident was published on 24 October 2023. RAIB made 10 safety recommendations in its report. Recommendation 5, which has been closed, is relevant to the circumstances of the accident at Talerddig. Four further recommendations of relevance to Talerddig from this investigation report are currently being implemented and are described in the next section of this report.

433 Recommendation 5 reads as follows:

The intent of this recommendation is for Network Rail to improve wheel-rail adhesion conditions through the application of improved understanding of the effectiveness of railhead treatment regimes.

Network Rail should undertake research to better understand:

a. the factors that affect the rate of build-up of leaf fall contamination, for instance, the environment, meteorological conditions, topography, tree species and railway operations

b. the relationship between different types of contamination and low railhead adhesion

c. the effectiveness and longevity of currently available alternative railhead treatment regimes.

The findings from this research are to be used to support the seasons delivery specialist in decision-making relating to the necessary frequency of railhead treatment and understanding the impact of missed or delayed treatment.

434 In August 2025 ORR reported that, in response to the recommendation, RSSB had undertaken a knowledge search which ORR considered to be detailed and thorough. The research found the high-pressure water jets used on the RHTT fleet to be currently the most effective control. The research also found a lack of a consistent testing methodology for railhead treatment methods and products. In addition, the impact of different treatments and methods when used together was not well understood. ORR reported that it challenged Network Rail to explain how the findings from the research may be used to support seasons delivery specialists in decision-making regarding railhead treatment. ORR stated that Network Rail plans to conduct laboratory tests of different treatment methods and products, with consideration given to the impact of using different treatments together.

435 ORR considered on this basis that the recommendation had been considered and action taken to close it.

Recommendations that are currently being implemented

Collision between passenger trains at Salisbury Tunnel Junction, Wiltshire, 31 October 2021, RAIB report 12/2023

436 Recommendations 2, 6, 9 and 10 from this report are relevant to the circumstances of the accident at Talerddig and are currently being implemented.

437 Recommendation 2 reads as follows:

The intent of this recommendation is for Network Rail to have seasons delivery specialists that are more effective in managing Network Rail's seasonal risk.

Network Rail, building on the work that has already started in this area, should develop an appropriate competency framework for the role of the seasons delivery specialist.

This framework should include:

a. a job description that accurately reflects the responsibilities of the role

b. the necessary technical skills required to undertake the role effectively

c. the necessary non-technical and management skills needed to undertake the communication and co-ordination required of this role

d. appropriate training material

e. arrangements to confirm that staff have achieved, and continue to have, the required level of competence.

Network Rail is to arrange for provision of the necessary staff to fulfil the roles and develop a time-bound programme for implementation of the associated training, supported by suitably qualified assessment staff

438 In October 2024, ORR reported that Network Rail had issued the seasonal development specialist competence framework and was developing the associated competence management arrangements and training. ORR stated that it would provide a further update, and that the recommendation remained open.

439 Recommendation 6 reads as follows:

The intent of this recommendation is to enable the effective assessment by Network Rail of the risk of overrun at signals which have HRLA sites on their approach.

Network Rail should review its signalling standard NR/L2/SIG/14201/Mod04, 'Signalling Risk Assessment Handbook' to ensure that signal overrun risk assessments appropriately consider the impact of any high risk of low adhesion sites on approach to the signal. Network Rail should also consider if the reassessment of signal overrun risk is required when a new high risk of low adhesion site is identified on approach to any signal capable of displaying a red aspect.

Any revised standard or process should be suitably briefed to all relevant parties and consideration should be given to whether a revised overrun risk assessment against the new standard should be required where existing signals capable of displaying a red aspect have a high risk of low adhesion site on their approach.

440 In October 2024, ORR reported that, in response to this recommendation, a request for help was sent to RSSB and that, as a result, the draft issue 2 of Rail Industry Standard RIS-0386 on signal overrun risk evaluation and assessment will contain new guidance on the management of low railhead adhesion (see paragraph 446). ORR also reported that Network Rail was planning a research project to determine what the new RIS means for their internal signalling risk assessment standard. ORR stated that it would provide a further update, and that the recommendation remained open.

441 Recommendation 9 reads as follows:

The intent of this recommendation is for industry to realise the potential benefits of future technologies to enable trains to better cope with low wheel-rail adhesion when braking.

The Rail Delivery Group working with the train operating companies and Rail Safety and Standards Board should create a framework and mechanism for the assessment of future technologies to enable trains to better cope with low adhesion when braking.

The framework should set out criteria and establish the process for cost benefit analysis to apply to the assessment of future technologies as they arise.

442 In October 2024, ORR reported that the Rail Delivery Group was co-ordinating industry action to address this recommendation through a steering group which included themselves, Network Rail, RSSB, and representatives from train operators and owners. RSSB and RDG planned to create a framework for the assessment of technologies and business plans including cost to benefit ratio. ORR stated that it would provide a further update, and that the recommendation remained open.

443 Recommendation 10 reads as follows:

The intent of this recommendation is to minimise the risk that passengers are unable to evacuate from class 158 and 159 carriages.

Porterbrook, Angel Trains and Eversholt Rail, working in conjunction with the operators of class 158 and class 159 trains, should review the design of the internal sliding doors on these carriages and determine if there is a practicable means to prevent these doors becoming jammed in the event of a collision.

They should develop a time-bound plan to implement measures identified by this review.

444 In October 2024, ORR reported that, in response to the recommendation, Porterbrook, Angel Trains and Eversholt Rail had funded research to consider the failure mode and possible changes to the design of vestibule doors on class 158 and 159 the output of which was still undergoing cost-benefit analysis. ORR stated that it would provide a further update, and that the recommendation remained open.

445 The above recommendation addressed a factor affecting the severity of consequences identified in this investigation. To avoid duplication of a recommendation which is currently being implemented, it is not remade in this report.

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

446 RSSB has published issue 2 of Rail Industry Standard RIS-0386-CCS, 'Overrun Risk Evaluation and Assessment' dated March 2025. This standard, which replaced Railway Group Standard GI/RT7006, does not support the generic use of a simple overrun risk assessment based solely on the provision of automatic train protection as was permitted for the Cambrian lines ERTMS scheme (paragraph 267). It also includes new guidance on the management of low railhead adhesion.

Other reported actions

447 TfWRL raised a national incident report (NIR, a rail industry system used to share urgent technical information) in the immediate aftermath of the accident advising the industry that the sand delivery hoses were found to be blocked. This was subsequently followed by a second NIR, advising the rail industry of the electrical defects discovered within the automatic sanding system (paragraphs 162 and 167).

448 TfWRL has modified its class 158 units so that operation of the sander test buttons now includes the SIS and LSR4 relay within the test circuit. This is intended to reduce the risk of dormant or intermittent failures within the automatic sanding system (paragraph 360).

449 TfWRL has briefed its drivers on the appropriate use of the emergency sanding system (paragraph 203).

450 Angel Trains has started a design review of the automatic sanding system of the same design as that fitted to TfWRL class 158 trains with a view to identifying any further possible dormant fault conditions. It has also started a review of maintenance practices across all fleets fitted with similar sanders, using the RSSB's 'Sander maintenance good practice guides' (RSSB project T1210) as a benchmark. A technology review is also being undertaken to identify existing and emerging technology for sander health monitoring and/or sand flow detection (paragraph 356).

Recommendations and learning point

Recommendations

451 The following recommendations are made:[27]

1 *The intent of this recommendation is to seek improvements in the standards relating to the design, maintenance and testing of trainborne automatic sanding systems to reduce the likelihood that such systems will not deliver sand when required.*

The Rail Safety and Standards Board, working in conjunction with the owners and operators of rolling stock fitted with sanding equipment, and using recognised rail industry processes, should review and update the standards and guidance relevant to the design, maintenance, and testing of trainborne sanding equipment.

This review should consider the critical nature of sanding systems in ensuring the safe operation of trains. It should also consider how such systems can be designed to eliminate potential modes of failure such as those detailed in this report or, where this is not possible, to make such failures readily identifiable to staff during routine preparation for service and during operational use. The review should also specifically consider the requirements around sanding system testing, and the need for testing functions to fully prove the electrical circuitry necessary for the correct operation of this equipment. It should also ensure that appropriate provisions exist for managing sanding equipment found to be defective.

The Rail Safety and Standards Board should develop a timebound programme for the implementation of any appropriate improvements to standards and guidance identified by this review (paragraphs 420b and 421c).

[27] 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.

2 *The intent of this recommendation is to improve the availability of the sanding system fitted to class 158 trains.*

Angel Trains, working in conjunction with the operators and other owners of class 158 trains, should continue its review of the design and maintenance of the automatic sanding systems fitted to these units. The review should seek to eliminate potential modes of failure (such as those detailed in this report) or, where this is not possible, to make such failures readily identifiable to staff during routine preparation for service and during operational use.

This review should specifically consider the requirements around sanding system testing, and the need for testing functions to fully prove the electrical circuitry necessary for the correct operation of this equipment. It should also ensure that appropriate provisions exist for managing sanding equipment found to be defective.

The review should also consider if the systems on class 158 trains are delivering optimum sand rates, taking into account rail industry good practice including (but not limited to) the Adhesion Research Group guidance (in the adhesion manual) and RSSB project T1210 Sander good practice guides.

Following completion of the review, Angel Trains should develop a timebound programme for the implementation of any appropriate improvements to the design maintenance and testing arrangements of the automatic sanding systems on class 158 trains.

Once any changes are implemented, Angel Trains working in conjunction with the operators and other owners of class 158 trains should establish an appropriate system to review the performance of these systems and to determine if the risk of trains operating with defective sanding equipment has been reduced so far as is reasonably practicable.

This recommendation may apply to the owners and operators of vehicles fitted with similar types of automatic sanding systems (paragraphs 418a.ii, 420b and 421c).

3 *The intent of this recommendation is to ensure the assumptions made allowing the use of simple overrun assessments on the Cambrian lines are still valid.*

Network Rail, working in conjunction with Transport for Wales Rail Limited, should review the assumptions which formed the basis for the decision to undertake a simple overrun risk assessment on the Cambrian lines.

This review should consider the validity of these assumptions against the circumstances of this accident, including the reliance on automatic sanders to achieve the intended brake performance, and how the gradient and layout features of Talerddig loop contributed to the severity of the overrun. It should also consider any relevant guidance in issue 2 of Rail Industry Standard RIS-0386-CCS 'Overrun Risk Evaluation and Assessment'.

If these original assumptions are found to be invalid, consideration should be given to undertaking overrun risk assessments in accordance with Rail Industry Standard RIS-0386-CCS issue 2 (paragraphs 418b.ii and 420a).

4 *This recommendation is intended to improve the system response to an overrun protection within future software-based train control systems.*

Network Rail should consider the opportunity to protect trains approaching the location of a potential exceedance of movement authority at the earliest opportunity as part of its client requirements specification for software-based train control systems. This could include features such as targeted stop commands being automatically issued to other trains approaching a potentially conflicting location at the point the system has had to intervene with an emergency brake application (paragraphs 418b.ii and 420a).

5 *The intent of this recommendation is to ensure that Transport for Wales Rail Limited understands how train drivers are interacting with the ERTMS signalling system fitted to the Cambrian lines and that appropriate guidance, training and assurance arrangements are in place to ensure that any risks not managed by automatic train protection, such as low adhesion, are being appropriately controlled.*

Transport for Wales Rail Limited, working with Network Rail and other rail industry bodies as required, should:

- understand how its drivers are interacting with the ERTMS signalling system, and the reasons for any practices identified, such as a lack of understanding of the system, operational pressures, or underlying organisational and cultural issues

- undertake a risk-based review of the policies, procedures, guidance, training and competency management systems relating to driving in ERTMS areas to ensure that these are appropriate, effectively control risk, and incorporate industry good practice
- work with Network Rail to minimise the effect of the 'warning masking' issue identified by this investigation
- ensure that all relevant data from ERTMS sub systems is made available and considered when carrying out post-incident investigations and reviews of driver performance.

Following completion of the review, Transport for Wales Rail Limited should develop a timebound programme for the implementation of identified improvements in operating policies, procedures, guidance, training, competency management systems and assurance.

This recommendation may apply to other transport undertakings operating trains in areas with ERTMS signalling systems (paragraphs 418a.iii, 420a and 420c).

6 *The intent of this recommendation is to fully equip train drivers with the necessary skills to act appropriately in the event of an emergency.*

Transport for Wales Rail Limited should undertake a risk-based review of its training, development and assessment processes for drivers to ensure that they are effective at ensuring that train drivers are competent in actions which may be required in abnormal or emergency situations, and that this competency is appropriately maintained.

This review should specifically consider the competencies relating to:

- making emergency calls
- the use of emergency sanding systems.

Following the review, TfWRL should develop a timebound plan to implement any appropriate changes identified.

This recommendation may apply to other transport undertakings (paragraphs 418a.ii, 419a and 420d).

7 *The intent of this recommendation is for Network Rail to improve wheel-rail adhesion conditions through the application of improved understanding of the effectiveness of railhead treatment regimes.*

Network Rail should continue its programme of research and testing to develop a more comprehensive understanding of the effectiveness and longevity of railhead treatments.

A suitable plan should be devised to implement any actions identified as required by this research and testing. This should specifically consider how the results should inform the training, instructions, and guidance to regional seasonal delivery staff on the expected performance of such treatments (paragraphs 418a.i, 418b.i, 419b, 419c and 420e).

8 *The intent of this recommendation is to ensure that the National Technical Rules governing the design of passenger train interior fittings reduce the risk to passengers in the event of an accident.*

The Rail Safety and Standards Board working in collaboration with rail vehicle owners and passenger train operators, and using recognised rail industry processes, should undertake a review of issue 6.2 of Railway Group Standard GMRT2100, 'Rail Vehicle Structures and Passive Safety'.

This review should consider the findings of this investigation and the requirements within this standard regarding the design and integrity of rail vehicle interior fittings such as tables. It should seek to establish if the current requirements in the standard should be changed to further reduce the risk of injury to passengers in the event of an accident.

The review should also consider when the requirements of this standard should be applied retrospectively to existing rail vehicles and, if so, when this should be, such as when carrying out refurbishment.

The review should consider the content of RIS-2700-RST, 'Verification of Conformity of Engineering Change to Rail Vehicles' to ensure that changes which are made to railway vehicles which could affect the passive safety of vehicle occupants are always subject to an appropriate level of engineering design and conformance to standards review.

The Rail Safety and Standards Board should develop a timebound programme for the implementation of any appropriate improvements to standards and guidance identified by this review (paragraphs 419d, 419e, 419f and 419g).

9 *The intent of this recommendation is to ensure that all members of on-train staff working for Transport for Wales Rail Limited have the skills and knowledge required to act appropriately in the event of an emergency.*

Transport for Wales Rail Limited should undertake a risk-based review of the competencies required of staff whose duties require them to regularly work on trains and interact with passengers, including staff undertaking non-safety-critical duties.

This review should consider the circumstances of this accident and evaluate whether these staff require further training, development, or assessment to ensure they are equipped to assist passengers effectively during abnormal or emergency situations.

The review should specifically consider scenarios in which other safety-critical personnel (such as train drivers) may be incapacitated or otherwise occupied with emergency response duties.

This recommendation may apply to other passenger train operators (paragraph 421b).

Learning point

452 RAIB has identified the following learning point:[28]

1 This accident underlines the importance of those with lead responsibility for safety-critical conversations establishing a clear understanding with drivers in accordance with the railway Rule Book so that appropriate actions can be taken to ensure the safety of the line and train operations (paragraph 419a).

[28] 'Learning points' are intended to disseminate safety learning that is not covered by a recommendation. They are included in a report when RAIB wishes to reinforce the importance of compliance with existing safety arrangements (where 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

Abbreviation / acronym	Term in full
ART	Autumn response team
AWS	Automatic Warning System
DfT	Department for Transport
DMI	Driver-Machine Interface
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
GSM-R	Global System for Mobile Communications – Railway
HRLA	High risk of low adhesion
JRU	Juridical Recording Unit
LSR	Low-speed relay
NIR	National Incident Report
ORR	Office of Rail and Road
OTDR	On-train data recorder
REC	Railway emergency call
RETB	Radio Electronic Token Block
RHTT	Railhead treatment train
RSSB	Rail Safety and Standards Board
SBI	Service brake intervention
SDM	Seasons delivery manager
SIS	Sander isolation switch
TfWRL	Transport for Wales Rail Limited
TGA	Traction gel applicator
TPWS	Train Protection and Warning System
WSP	Wheel slide protection
WSPER	WSP Evaluation Rig

Appendix B - Investigation details

RAIB used the following sources of evidence in this investigation:

- information provided by witnesses
- information taken from the OTDRs and JRUs of the trains involved and other trains that had passed through Talerddig
- CCTV recordings taken from both trains involved
- site photographs and measurements
- weather reports and observations at the site
- analysis of data recorded by the signalling system with respect to the passage of both trains
- laboratory analysis of samples taken from the railhead on the approach to the site from Talerddig loop
- testing of ERTMS on a class 158 train approaching Talerddig loop
- examination and testing of the braking, WSP system, automatic sanders and emergency sanding systems of the trains involved
- testing and simulation using WSPER
- reconstruction and testing of the automatic sanders from train 1J25
- a review of previous RAIB investigations that had relevance to this accident.

Appendix C - The class 158 automatic sanding system and the pneumatic faults on the automatic sanding system on vehicle 57841

C1 This appendix:

- describes the applicable standards, sand delivery rate requirements, maintenance requirements and maintenance history for the class 158 automatic sanding system
- provides further information on the class 158 automatic sanding system design and its principles of operation
- describes RAIB's examination of the automatic sanding system on vehicle 57841, including the faults found within the pneumatic assembly
- describes a restriction found in the driver's side sand delivery hose
- discusses the sand delivery rates, including benchmark testing undertaken by RAIB to estimate the likely sand delivery rate at the time of the accident.

Applicable standards, maintenance requirements and maintenance history

C2 The use of sanders on trains is governed by Railway Group Standard GM/RT2461, 'Sanding Equipment'. The first issue of this standard, dated August 2001, included requirement 9.3.1:

- *'The sand deposition rate per rail during braking shall be such that the rear two axles of the multiple unit do not come to rest on sand laid at a rate of 7.5 grams/metre or greater', and*
- *'A recognised method of achieving the above is a laying rate approaching, but not exceeding, 2 kg/minute per rail when using a full service or emergency brake application'.*

C3 Issue 2 of GM/RT2461, dated June 2016, provided additional information about the sand delivery rate in requirement 2.4.1:

- *'Sand deployed by trainborne sanding equipment shall not adversely affect the operation of track circuits'.*

It also provided guidance about complying with the requirement, including:

- *'the sanding system is installed and designed such that the last two wheelsets of the train formation do not come to rest on sand laid at a rate of 7.5 grams / metre / rail or greater. This is based on the ability of low voltage track circuits to detect a train when sand is present between the wheel and rail. This has been achieved for braking sanders by using a fixed rate sander depositing sand at a rate of 2 kg / minute / rail that can be used down to a speed of 10 mph or higher'.*

C4 Issue 1 of GM/RT2461 also included the following requirements:

- *'7.1 Isolation of sanding equipment. Means shall be provided for isolating the sanding equipment. Suitably positioned reminder(s) located in the driving cab and visible to the driver shall indicate the sanding function not available if isolation has been performed'.*

- *‘8.2 System integrity and reliability. The sanding equipment and all other systems and equipment that provide input to the sanding equipment system shall be designed and maintained to ensure that braking performance is not jeopardised. Overall reliability of the sanding equipment shall be considered at the design stage’.*
- *‘8.5 System testing facility - A manual test facility shall be provided on the vehicle underframe. The facility shall: a) test as much of the system functionality as practicable, b) permit observation of the sand discharging’.*

C5 The design file for the class 158 unit automatic sanding system includes a document called ‘Technical description class 158 sanding system upgraded with step 2 sanding’, issue 1, dated January 2007. This states that the automatic sanding system was designed to comply with the requirements of issue 1 of GM/RT2461, albeit with a temporary non-compliance to enable sanding in brake step 2 (as well as in full service and emergency braking). The document also states that ‘*the sand delivery rate will be set at 2 kg / min / rail as specified in GM/RT2461 to ensure track circuit actuation is preserved under all conditions*’.

C6 The same file also included a document called ‘Class 158 sander - maintenance instructions applicable to units fitted with step 2 sanding modification’, issue 1 dated January 2007. This provides the basis for the sander maintenance instructions:

- *‘Press the sander test button for 30 seconds and catch the discharged sand from the delivery hose into the container. Weigh the amount of sand taking into account the weight of the container and check the amount of sand discharged is between 0.6 kg and 1.0 kg’.*

C7 The corresponding TfWRL maintenance procedure for checking the sand delivery rate is ASS0632 ‘Sanding System Discharge Test’, issue 3 dated November 2013. This includes the following procedure:

- *‘1.1 Weigh two suitable containers prior to use that will hold in excess of 2 kg of sand each (an empty sand bag makes a suitable container and the weight can be ignored for practical purposes)’.*
- *‘1.2 Ensure the containers fit over each sander delivery/discharge hose. Press the sander test button for a few seconds to prime the hoses and discard the sand. Then press the sander test button for 30 seconds and catch the discharged sand from the delivery/discharge hoses into the container’.*
- *‘1.3 Weigh the amount of sand in each container taking into account the weight of the container and check that the amount of sand discharged is between 0.75 kg and 1.0 kg per container. If the amount of sand discharged is over or under these limits investigate the reason and rectify’.*
- *‘1.4 Record the amount of sand discharged on the exam block card’.*

C8 The TfWRL maintenance system recorded procedure ASS0632 as completed on unit 158841 on 25 September 2024 (26 days before the accident). However, the record does not capture the actual sand weight discharged during the test. Although procedure ASS0632 states the data should be captured on an exam block card, there was no facility to enter this data into the maintenance recording system used by TfWRL.

C9 RSSB provides guidance on multiple unit sander maintenance in its document 'Sander maintenance good practice guide', issue 1 dated March 2022 (T1210). This highlights the importance of sanding equipment, demonstrates the potential benefit (in terms of stopping distance) provided by sanders in low adhesion conditions, and summarises some low-adhesion incidents investigated by RAIB. The document describes 38 items of good practice/advice for maintaining sanding equipment.

C10 The 'Managing low adhesion' manual (paragraph 70) notes that *'sander maintenance is a safety critical activity and should have equal importance to brake system maintenance. Good practice in sander maintenance includes… measuring sand discharge rates and correcting where necessary*.

TfWRL Class 158 automatic sanding system – design and operation

C11 Each TfWRL class 158 vehicle has a single sand hopper, mounted on the underframe on the non-driver's side ahead of the third wheelset. Below the sand hopper are two sand valves, with a sand delivery hose attached to the bottom of each sand valve (one to supply sand to the left wheel, and one for the right wheel). The sand valves are made from malleable cast iron and are sometimes referred to as 'castings' or 'shoes'.

C12 Sand falls from the hopper and fills the void in the sand valve. The sand valve has a built-in 'weir' and the sand naturally settles against this, preventing sand from falling down the sand hose when not in use. A sand valve is shown in figure C1 and a schematic cross-section is shown in figure C2.

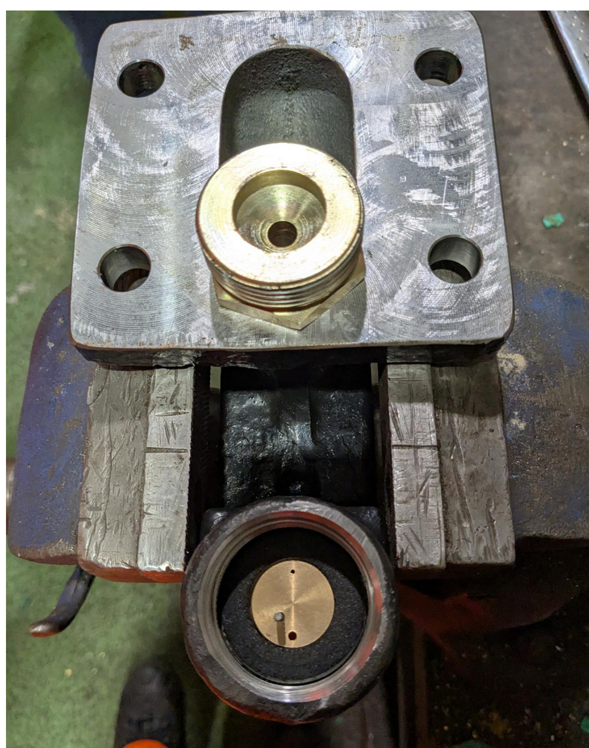

Figure C1: Example sand valve, showing some of the internal components (the image shows a brand new valve).

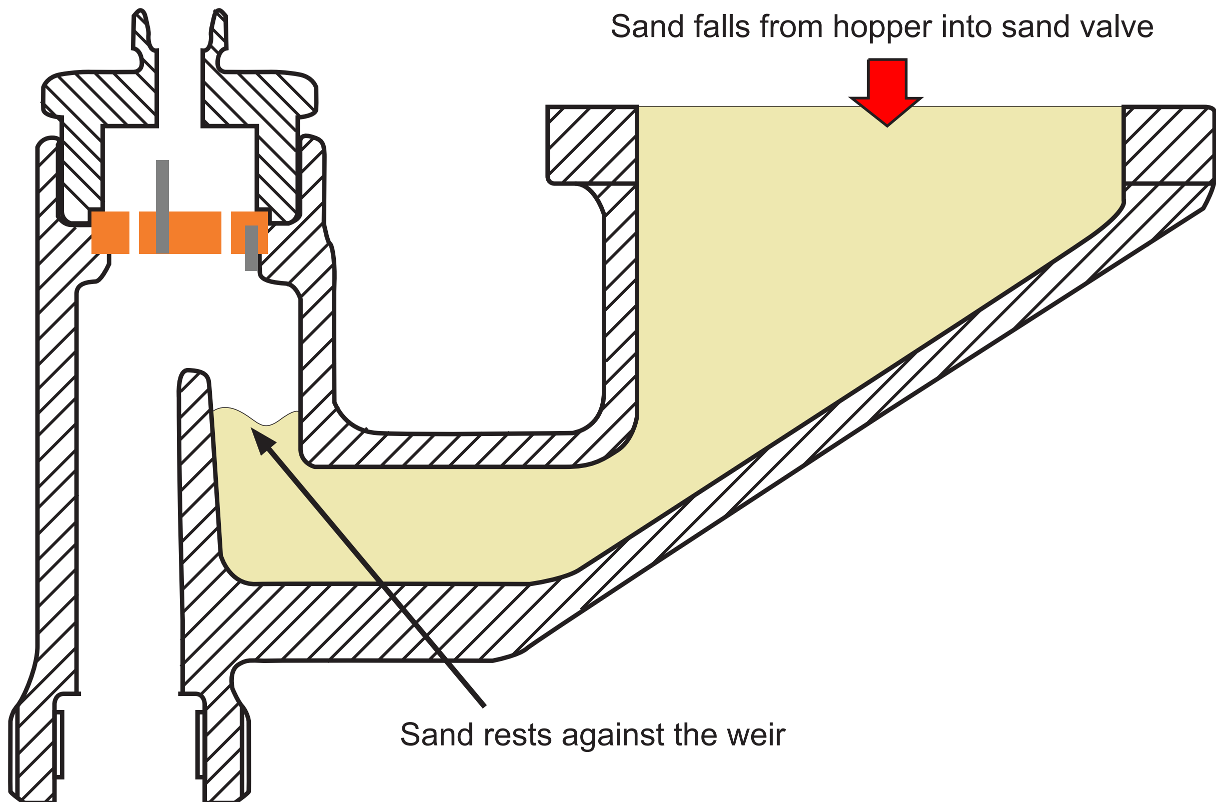

Figure C2: Cross-section of sand valve casting when sand is not being delivered.

C13 When sand is needed, compressed air is admitted to the top of the sand valve from the train's main reservoir system. This is at a nominal pressure of 7 bar. The admission of air is controlled by a solenoid-operated valve; paragraph 159 provides information on the electrical control system which operates this valve.

C14 Air flowing through the sand valve is controlled by the 'orifice plate' (sometimes referred to as a 'venturi plate'). The orifice plate is machined from hard brass and features two holes:

- A smaller (approximately 1 mm) hole is positioned above the sand on one side of the weir, and the jet of compressed air that passes through this hole acts to fluidise the sand.
- A larger (approximately 2 mm) hole is positioned directly above the port for the sand delivery hose, such that the jet of air will draw the fluidised sand over the weir and carry it down the delivery hose.

This arrangement is shown in figure C3.

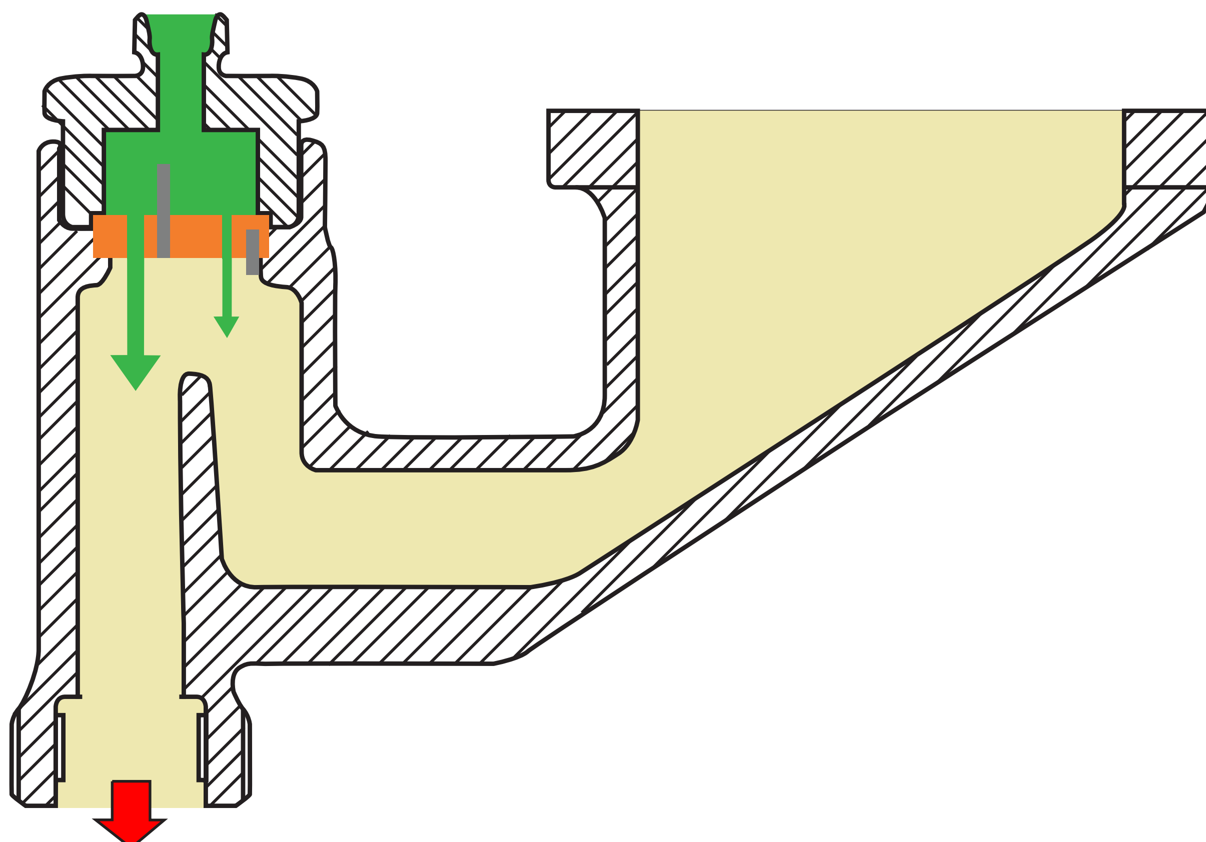

Figure C3: Cross-section of sand valve casting when sand is being delivered. The green colour denotes flow of compressed air.

C15 The orifice plate also features two steel pins:

- A longer (15 mm) pin is installed towards the centre of the orifice plate, and its function is simply to enable the plate to be handled (to aid installation/removal). When placed into the sand valve casting, this pin should be pointing upwards.
- A shorter (8 mm) pin is installed near to the edge of the orifice plate, and its function is to engage with a cut-out in the sand valve casting to ensure the orifice plate is correctly oriented. This pin should be pointing down when installed in the sand valve casting.

An example of a new orifice plate installed in a new sand valve casting is shown in figure C4. Note the correct orientation of the holes and pins.

Examination of pneumatic sanding equipment on vehicle 57841

C16 Shortly after the accident, RAIB removed the sand delivery hoses from vehicle 57841. RAIB then undertook preliminary testing by pressing the sand hopper test button. Although there were no sand hoses installed, dry sand flowed freely from each sand valve during the test.

C17 When the sand valves from vehicle 57841 were removed it was noted that the orifice plates were incorrectly installed. The orifice plates inside both sand valves were upside down and were rotated out of alignment. In particular, the orifice plate in the non-driver's side sand valve was significantly misaligned and its sealing washer was also missing.

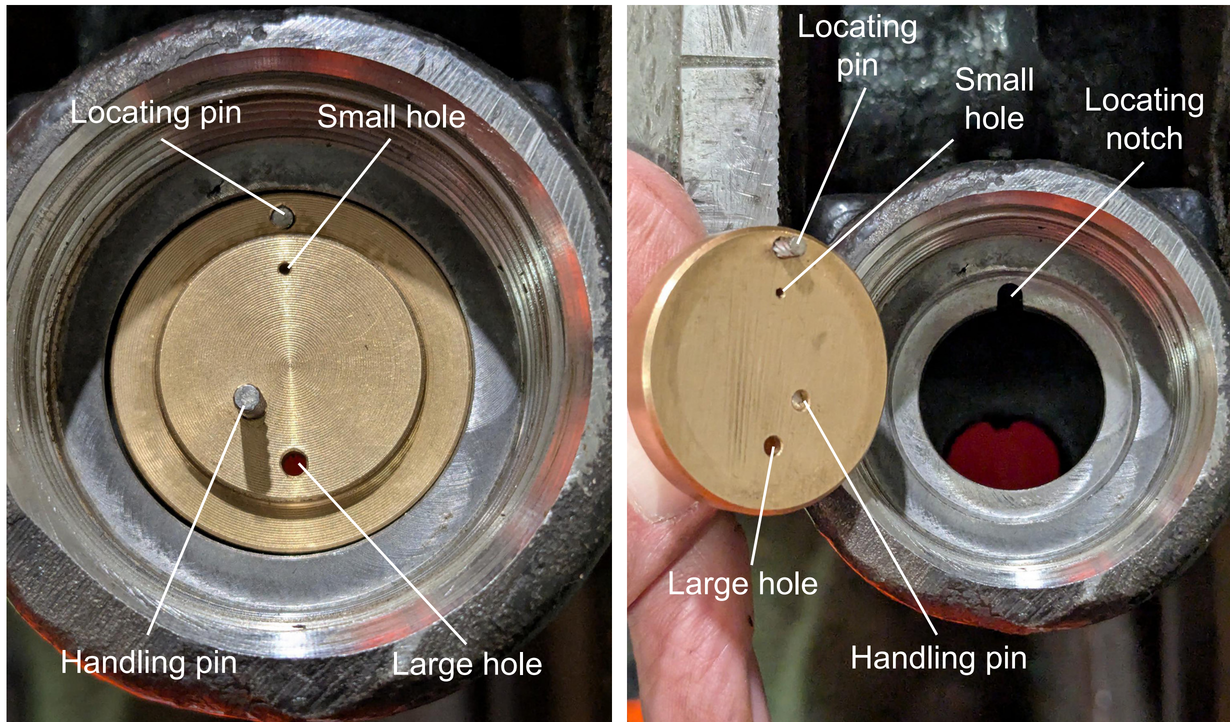

Figure C4: New orifice plate installed in a new sand valve casting (left) and during assembly showing locating pin and corresponding notch (right).

C18 During the disassembly, in order to access the orifice plate in the non-driver's side sand valve, the threaded cover nut was removed. As this was unscrewed, the orifice plate was rotated again. However, there were witness marks within the casting and the cover nut which enabled RAIB to estimate the orientation of the orifice plate at the time of the accident. RAIB estimated that, at the time of the accident, the orifice plate was rotated by approximately 80° anti-clockwise out of alignment, as shown in figure C5.

C19 A consequence of installing the orifice plate upside down is that the locating pin (which should be pointing down to engage with the notch in the casting) was pointing up and therefore could not engage with the alignment notch. The pin had instead interfered with the cover nut when it was screwed into place, deforming the pin and causing the orifice plate to rotate.

C20 The consequence of the misalignment is that the orifice plate holes were not directing the jets of air in the as-designed directions. The two holes in the orifice plate, which are designed to be on opposite sides of the weir, were aligned almost in line with the weir. This means that, during operation, the compressed air was not moving through the valve in the way it was designed. This was likely to have negatively affected the sand delivery rate.

C21 The sand valve casting will naturally experience wear during its service life, and this typically manifests as a thinning of the weir (since this is where the sand flow is most energetic and the sand particles will wear away the cast iron material). A new (unused) sand valve is shown on the left of figure C6 and the unworn weir can be seen inside the valve. The weir has a flat edge where it meets the sand (indicated with a yellow dashed line), and the other side of the weir is curved for the outlet port (orange dashed line).

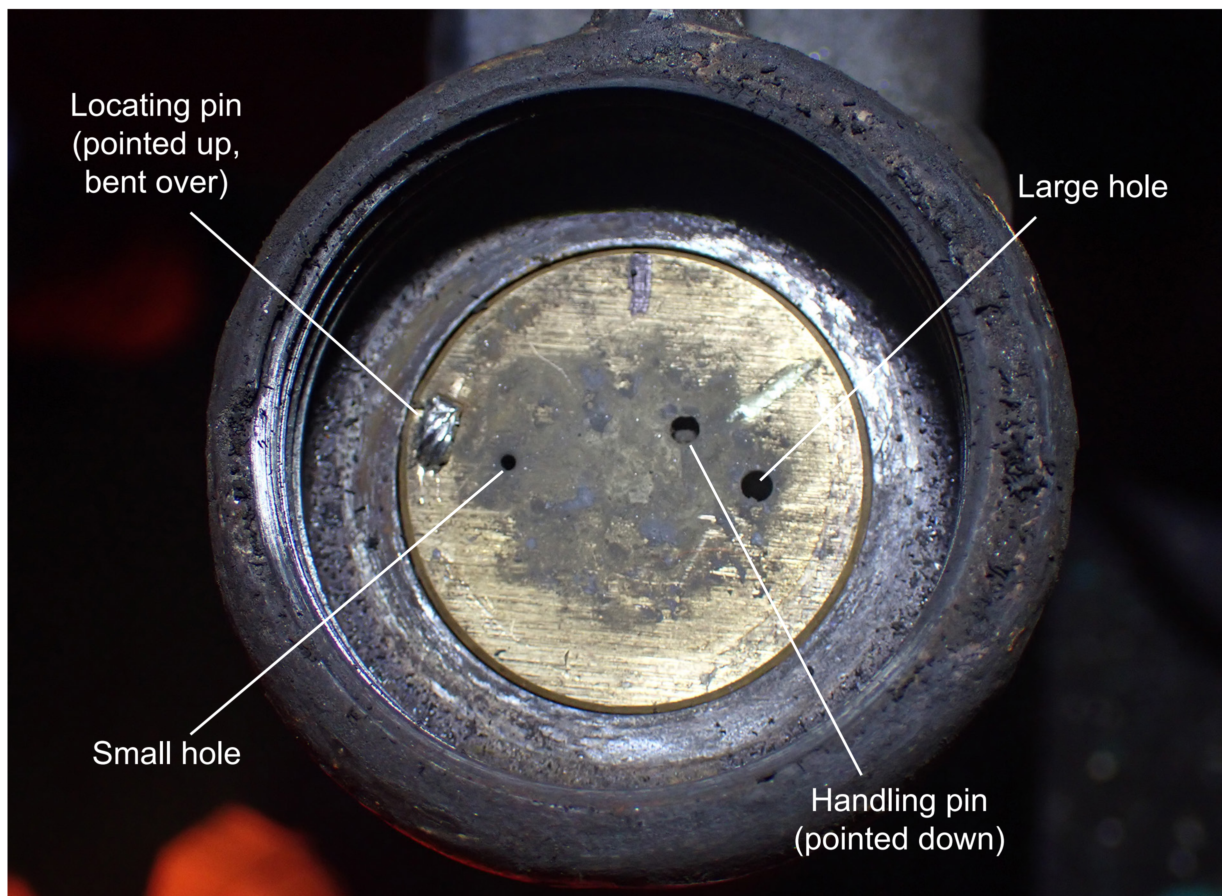

Figure C5: Sand valve casting from non-driver's side of 57841, after partial reassembly to demonstrate the orientation at the time of the accident.

C22 The centre image of figure C6 shows a sand valve with typical wear which can be seen as a thinning at the centre of the weir. The right-hand image shows the sand valve from 57841, displaying an unusual wear pattern caused by the misaligned orifice plate. The circular hollow wear on the left of the weir was aligned with the small hole of the misaligned orifice plate, and the wear on the right of the weir is below the larger hole of the misaligned orifice plate. RAIB used this wear patten to determine the likely orientation of the orifice plate (as described in paragraph C18).

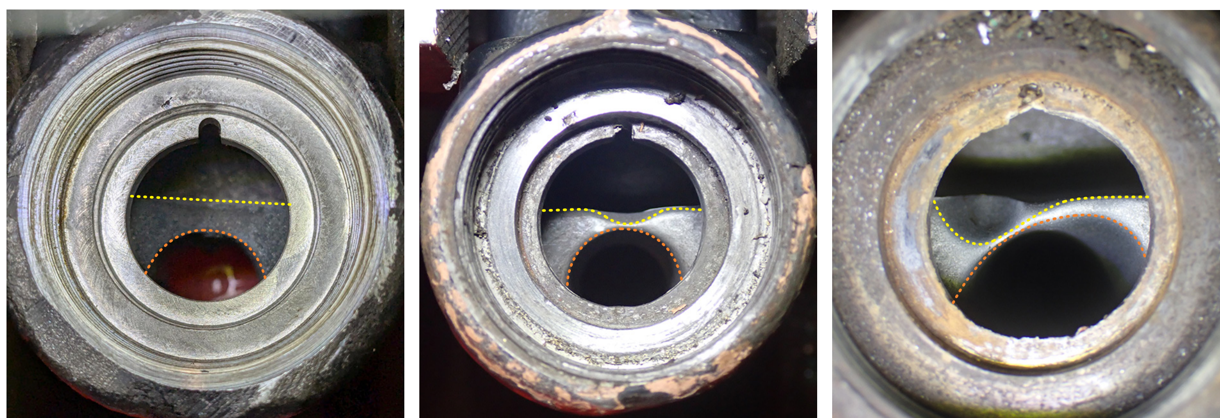

Figure C6: Sand valve weir wear: new valve (left), typically worn valve (centre) and unusual wear of 57841 valve (right).

C23 It was not possible to determine for how long the sand valve had been operating with the orifice plate incorrectly aligned. However, the extent of the observed wear suggests that the orifice plate had been in this orientation for an extended time.

C24 The technical description document (paragraph C5) states that the design includes orifice plates made of hard brass, since the steel orifice plates used on older sander designs were prone to rusting and premature failure. The orifice plates found in the sand valves of vehicle 57841 appeared to be constructed from brass; this contrasts with those found in the sand valves of vehicle 52841 which appeared to be steel. RAIB has not been able to determine why steel orifice plates were found in the sand valves of vehicle 52841, or when the incorrectly assembled brass plates were installed in the sand valves of 57841.

Partially constricted sand delivery hose

C25 The sand delivery hoses are connected to barbed fittings on the bottom of the sand valves. To ensure a good alignment, the hoses are supported at various points along their length, and the delivery end of each hose is connected to a bracket which is installed ahead of the corresponding wheel, similar to that used for rail vehicle lifeguards. The arrangement results in the sand being directed towards the wheel-rail interface. By design, the rubber hoses are bonded into metal 'pipe clips' and these pipe clips are then bolted to the brackets. The sander design file explains that the purpose of this arrangement is so that the hose can pull out if an object becomes entangled in the hose.

C26 RAIB inspected the sand hoses on 57841 after the accident and found that the sand hoses were not bonded into the pipe clips. Instead, hose clamps had been installed on either side of the pipe clip to secure the hoses in the pipe clips (figure C7).

C27 One of the hose clamps was deformed (figure C8). After cutting the sand hose near the hose clamp, the severity of the restriction to the air flow could be seen (figure C9). RAIB estimated that the hose clamp had reduced the cross-sectional area of the sand hose by approximately 60%.

C28 TfWRL Maintenance procedure ASS0630, 'Sander Lanyard & Bogie Bracket Security Check', issue A2 dated January 2021, states that *'sand hoses should be held in position using Silkaflex 221 adhesive and a jubilee clip either side of the bracket*'. ASS0630 also states that '*it is important that the dimension from the end of the hose to the bracket is correct and that the jubilee clips are not overtightened and reducing the pipe bore. This may indicate a softened hose which will require changing'*.

Figure C7: Sand hose securing arrangement showing lifeguard bracket, pipe clip and hose clamps used on 57841.

Figure C8: The sand hose taken from the driver's side of 57841. In this image, one of the hose clamps and the pipe clamp have been removed, leaving in place the deformed hose clamp.

Figure C9: After cutting the hose near the hose clamp, the restriction in the sand hose can be seen, accounting for approximately a 60% loss in cross-sectional area of the sand hose.

C29 RSSB document 'Sander Maintenance good practice guide' highlights the risk associated with using hose clamps on sand hoses and provides photographs of poor practice (figure C10).

Figure C10: Extract from RSSB Sander maintenance good practice guide showing poor practice with hose clamps (courtesy of RSSB).

Consideration of effect of pneumatic and mechanical defects on sand delivery rates

C30 As described in paragraph C8, the TfWRL maintenance recording system shows that the automatic sanding system on 57841 was tested on 25 September 2024 (26 days before the accident). The minimum sand delivery rate required to pass this test is 0.75 kg in 30 seconds (paragraph C7).

C31 To estimate the sand delivery rate for vehicle 57841 at the time of the accident, RAIB reconstructed the sanding system in its laboratory (paragraph 174). Testing was undertaken to understand the combined effect of:

- the condition of the sand valves, including the incorrect pneumatic assembly and the observed sand valve wear
- the sand delivery hose constriction caused by the hose clamp on the driver's side hose
- the asymmetrical hose arrangement of the class 158 vehicle, where the driver's side hose is longer than the non-driver's side hose (paragraph 400).

C32 The results of the testing were that, had the sanders been operative at the time of the accident:

- the driver's side (longer sand hose) with the hose constriction could have delivered approximately 0.16 kg in 30 seconds
- the non-driver's side (shorter sand hose) could have delivered approximately 0.56 kg of sand in 30 seconds.

The average of left and right sand delivery hoses is therefore 0.36 kg in 30 seconds (which can also be expressed as 0.72 kg per minute).

C33 To undertake this testing, RAIB used components from the sanding system of vehicle 57841. Some of these components had been previously disassembled as part of the investigation. Although RAIB took care when reassembling the components, there are some potential variations:

- The orifice plate in the non-driver's side valve of 57841 rotated during initial disassembly of the valve. RAIB attempted to reinstall it in the same orientation that it was in at the time of the accident.
- New sand delivery hoses were used because the original sand hoses had been cut into small sections to enable visual inspection inside the hoses (see paragraph D1). The new hoses were cut to approximately the same length as the original ones.
- To facilitate the sand hose ejection testing (which was conducted before this sand delivery rate testing, see paragraphs 172 and C38), RAIB had removed the hose clamp from the sand delivery hose. RAIB reinstated the hose clamp, using before and after photography to ensure a similar constriction.
- The short section of constricted hose was joined to the new hose with a back-to-back coupling union.

C34 RAIB has also considered the nature of the pneumatic faults found in the sanding system and if these could have occurred as a consequence of the end-on collision of the train. RAIB has concluded that the faults described with sand valve assembly, sand valve wear and hose restriction all existed before the accident.

C35 The testing conducted by RAIB shows that, if the sanding system on vehicle 57841 been tested immediately before or after the accident, had the sanders been operative, it is possible that it would not have met the minimum sand flow requirement of 0.75 kg in 30 seconds as specified in ASS0632.

C36 The TfWRL maintenance system was interrogated to determine if class 158 units had a history of failing to meet the sand delivery rate requirement contained in ASS0632. There were no records of failures on class 158 trains in 2024 before the accident, and no records of failures in 2023. However, it is possible that if any faults were identified during routine ASS0632 testing, then remedial work would have been undertaken, the train retested and marked as complete without any details of the initial failure or remedial work being entered into the system. This means that the lack of any recorded failure data is not necessarily an indication of a lack of identified faults or remedial work.

C37 Shortly after the accident, TfWRL undertook a maintenance campaign to retest sand delivery rates on the class 158 fleet. This identified six class 158 units which failed the sand delivery rate retest; some of these had serious faults which considerably reduced the sand delivery rate, sometimes on multiple sanders of each train. Most of the faults required remedial work to bring them back into specification.

Consideration of the effect of pneumatic and mechanical defects on the ability of an electrically active sander to clear sand delivery hose blockages

C38 As described in paragraphs 172 to 176 and appendix D, RAIB conducted testing to determine if an electrically active sander could eject the hose blockages. The small portable compressor used for this testing was only able to supply compressed air at the correct pressure for a short period; therefore these hose unblocking tests were limited to short durations of sander activity (approximately 5 to 10 seconds). This testing included the fully blocked hose end from the driver’s side of 57841, which also had the hose constriction still in place caused by the deformed hose clamp.

C39 The sander was activated for a short period. While some of the blockage was ejected immediately, some remained in the end of the hose. After a second sander activation it was noted that, although air was coming out of the hose end, there was no sand delivery. Inspection revealed that sand was backed up inside the hose. After removing the hose clamp and this sand, a few further sander activations cleared the remainder of the blockage material from the hose and restored sand delivery.

C40 After the hose unblocking tests, RAIB subsequently reinstated the deformed hose clamp and conducted additional testing to estimate the sand delivery rate (paragraph C32). Because the sand delivery rate testing required 30 seconds of sand delivery, a larger air compressor was used which could supply compressed air at the required pressure for this duration. In these additional tests it was found that sand did not back up behind the deformed hose clamp.

C41 The build-up of dirt on the deformed hose clamp indicates that it had been in this condition for some time. The fuel point exam completed on the day before the accident verified that sand was delivered from both hoses with the clamp in place, indicating that sand was delivered past the clamp constriction. The build-up of sand behind the deformed hose clamp that RAIB observed is therefore possibly associated with the use of a small air compressor which had a diminishing air supply pressure during the test. The hose clamp on the non-driver’s side was not deformed and there was no constriction on that side.

C42 RAIB has concluded that, even with the deformed hose clamp, the driver's side hose connected to an electrically active sander is capable of clearing a total blockage of the type found in the sand delivery hoses of 57841, although some material might remain.

Appendix D - Analysis of the blocked sand delivery hoses and the origin of the material

Blocked sand delivery hoses

D1 After the accident, RAIB removed the blocked sand delivery hoses from vehicle 57841 for analysis. These hoses were examined in RAIB's workshop with the following observations:

- The examination was completed 11 days after the accident, and in the intervening period there was visible mould/mildew growth on the blockage material, indicating it contained organic material (figure D1).
- Although both hoses were blocked at the outlet end, there was no evidence of any significant build-up of sand in the pipe behind the blockage.
- Both hoses were cut into smaller sections, and visual inspection showed the insides of the pipes to be clean with no other obstructions except at the delivery end. This confirms that the blockage material had not come down the hose from the sand hopper.
- The driver's side hose was totally blocked with material, starting from approximately 5 mm inside the hose end, through to a depth of approximately 30 mm inside the hose. Leaf-like material was visible at the end of the hose. The blockage material was left in situ for later testing (paragraph 172).
- The non-driver's side was totally blocked and had a dome-shaped plug of material visible on the end of the hose, which extended approximately 30 mm deep inside the hose. This material was removed and subjected to further analysis.

Figure D1: The blocked sand delivery hoses from leading vehicle 57841 during inspection.

Analysis of hose blockage material

D2 RAIB commissioned a laboratory to conduct detailed testing on the plug of blockage material from the non-driver's side sanding hose of vehicle 57841. The sample was cut through the centre to show the cross-section. Examination of the cross-section revealed it to consist of lamellar layers of an organic-type material (figure D2). The cross-section was probed with a stylus to establish lamellar planes in which the material could be opened out and segregated.

Figure D2: The plug of material from the end of the non-driver's side hose after being cut in half.

D3 Examination revealed multiple layers and individually identifiable pieces of organic material such as a leaf stem and leaves (figure D3). DNA analysis was conducted on five of the observable layers within the plug of material. This revealed the dense organic material to be predominantly from ash trees, although other species such as acer and wild cherry were also identified towards the edges of the material.

Figure D3: Close-up of the plug of material showing the location of the five layers used for DNA testing.

D4 To analyse the mineral fragments, some of the blockage material was dissolved and centrifuged to separate the particles. High magnification examination revealed the majority of particles to be translucent, angular and less than 0.1 mm in size. These were compared to some known sources of minerals, including sand from the automatic sanding system, and sand extracted from adhesion modifiers. The particles found in the sand hose blockage material were significantly smaller and more angular than those in the reference samples (figure D4), suggesting they could be remnants of larger particles that had been crushed at the wheel-rail interface. The general appearance of the particles was similar in colour to those found in the TGA traction gel.

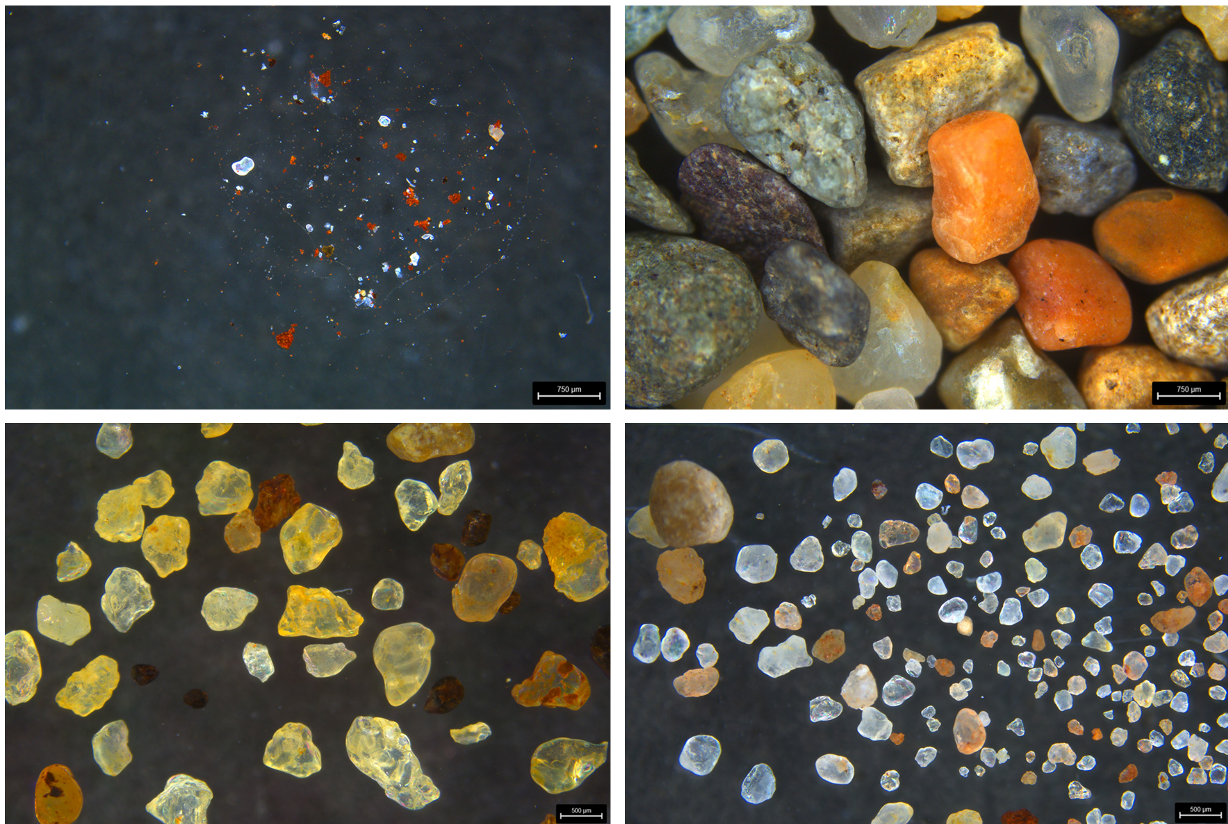

Figure D4: High-magnification images - top left: small particles of sand found in the hose blockage material; top right: sand from the train's automatic sander; bottom left: sand particles from traction gel delivered by RHTTs; bottom right: sand particles from TGA traction gel.

D5 The plug of blockage material was also subjected to mass spectroscopy testing to determine if it contained elements or compounds found in typical railway products. The testing found that the blockage material contained traces of long-chain hydrocarbons which were also found in reference samples of typical railway grease/lubricant. No railhead treatment/cleaning products were found in the blockage material.

D6 The plug of material also contained a curved piece of polymeric material, approximately 27 mm at its longest length with a thickness of approximately 0.4 mm. It was dark grey on one side and light grey on the other indicating that it consisted of two layers (figure D5). The piece of material was analysed by infra-red spectroscopy, with the results consistent with Ethyl Cyanoacrylate, which is commonly found in adhesives. During post-incident testing, RAIB examined the sanding system (including the contents of the sand hopper) and did not find any similar looking material. Although it was not possible to determine the origin of this piece of material, RAIB concluded that it most likely originated from an external source.

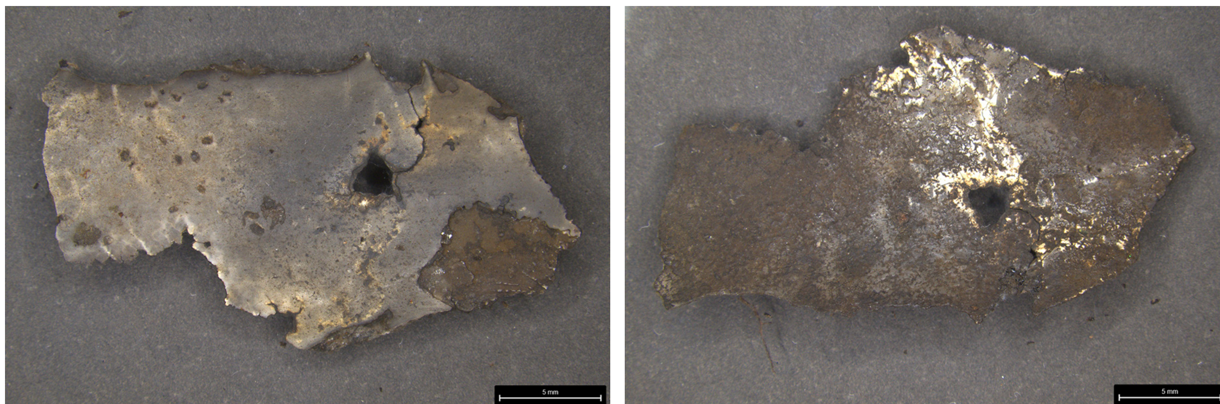

Figure D5: Curved piece of polymeric material found in the sand hose blockage material.

Possible timeline for sand delivery hoses becoming blocked

D7 It is not possible to know for certain when the sand hoses on unit 158841 became blocked. However, RAIB analysis has identified a time and location when this possibly occurred. The last known check of the sanding system was during the morning of 20 October 2024 when the train underwent a fuel point examination and was then prepared for service (paragraph 42). These checks verified that sand was discharged, meaning that the hoses were not blocked at this time, with the checks carried out using the sander test button.

D8 At 22:18 that day, a number of track circuit failures occurred on the up line at Gobowen. The signaller at Gobowen advised that multiple track circuits ‘blipped’ (briefly showing clear when occupied) while train 5G38, formed of unit 158818, was passing over. The details are captured on a Network Rail ‘National operating procedures - failure to operate track circuits report’ form. This identified intermittent track circuit failure and indicated the cause was ‘*not known but likely to be leaf fall contamination*’.

D9 Upon arrival at Shrewsbury, train 5G38 was examined and TfW advised that there was evidence of leaf contamination on the wheelsets which required cleaning off. Further track circuit failures occurred at Gobowen at 23:14 involving train 1D21, formed of unit 158830. Witness evidence from TfWRL technicians based at Machynlleth supports that on the weekend of 18 to 20 October several trains arrived at the depot with an unidentified green leafy residue on the wheels.

D10 After completion of the last passenger service at Shrewsbury on 20 October, unit 158841 was planned to be stabled overnight at Crewe maintenance depot. However, due to service disruption, the train was instead driven to Chester station and stabled in a platform, arriving just before midnight. This diversionary route to Chester took unit 158841 via the down line at Gobowen at approximately 23:20, with vehicle 57841 leading and 52841 trailing. Therefore, the sand hoses on this trailing vehicle (paragraph 81, figure 17) faced the direction of travel and consequently were 'at risk' of becoming blocked by material flicked up by the train wheels (figure D6).

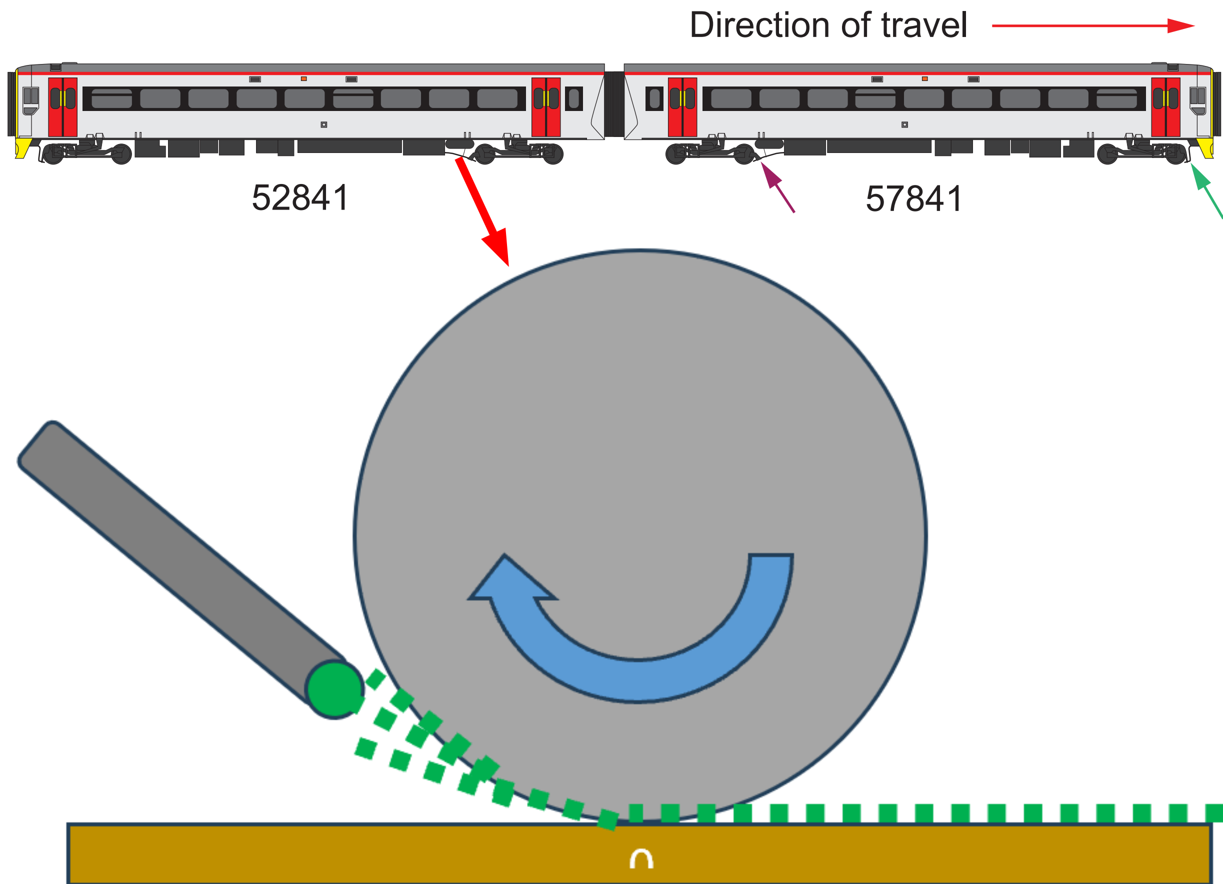

Figure D6: Automatic sanders on vehicle 52841 at risk of being blocked by material flicked up by the wheels.

D11 The train was then stabled overnight at Chester station, before passing through Gobowen again at approximately 04:40 on 21 October. On this journey, the train was travelling with 52841 leading and therefore the sand hoses on vehicle 57841, which were in a trailing direction, were now at risk of being blocked.

D12 The RHTT (paragraph 44) treated the down (northbound) line at Gobowen at 02:51 on 21 October, and the up (southbound) line at 06:33. This treatment schedule meant that train 158841 passed through Gobowen on each line before the RHTT cleaned the track.

D13 The available evidence, therefore, supports the theory that the sand hoses on 52841 could have become blocked as the train passed through Gobowen at 23:20 on 20 October. The train was then stabled overnight at Chester station, and it is possible that the sand hoses on 57841 became blocked as the train passed through Gobowen again at 04:40 the next morning. The available evidence shows that there was a significant quantity of suspected leaf contamination on the track at this time, such that other passing trains encountered wrong-side track circuit failures and needed their wheels cleaning.

D14 On the morning of 21 October, while stabled at Chester station, train 1J25 received an 'above solebar preparation' which did not include pressing the sander test button (paragraph 45). It is possible that the sand hoses on 52841 were blocked at that time, but the sand hoses of 57841 were not. It is likely (paragraph 176) that pressing the sander test button at this time would have ejected the blockage from the sand hoses of 52841.

D15 Although sander activity is not recorded on the OTDR of unit 158841, other data channels were scrutinised to determine if the train had encountered low adhesion which could indicate that the conditions for sander activation would have been met. Some of the journeys were completed with the train connected to another unit. TfWRL class 158 units are configured such that sanding is prohibited when the unit is the trailing one of a multiple unit (paragraph 159). Therefore, this data analysis also took account of the position and orientation of each vehicle within the train it was part of.

D16 In the period between passing through Gobowen at 23:20 on 20 October and the collision at 19:26 on 21 October, unit 158841 changed direction, and was coupled with other units several times, on different services:

- For two of these services, neither automatic sanding system on unit 158841 would have been available for use because it was coupled behind another unit.
- For two of these services, vehicle 52841 was the leading one and so the automatic sanding system on this vehicle would be enabled. Examination of OTDR data found no periods of fluctuating brake cylinder pressure, indicating that vehicle 52841 did not encounter low adhesion conditions while braking which would have demanded sand. This provides an explanation of why one of the sand delivery hoses on vehicle 52841 was found to be almost fully blocked with an accumulation of material, even though there were no faults with the sander electrical system on this vehicle.
- For six of these services, vehicle 57841 was the leading one and so the automatic sanding system on this vehicle would be enabled. Examination of OTDR data found several instances of fluctuating brake cylinder pressure between 05:30 and 09:20, which indicates that vehicle 57841 encountered low adhesion conditions while braking which would have demanded sand. RAIB has not been able to determine if these demands resulted in sand delivery from the available data.

D17 Of particular note is an event which was reported at 05:55 on 21 October by the driver of train 2D03 (the 05:31 train from Shrewsbury to Chester) which had vehicle 57841 leading. The driver reported poor adhesion conditions during periods of acceleration over a distance of approximately 12 miles between Shrewsbury and Gobowen. Examination of the OTDR data during this journey shows fluctuating brake cylinder pressure during step 2 and full service (step 3) braking, indicating that vehicle 57841 encountered low adhesion conditions while braking which would have demanded sand.

D18 At 06:05, the driver of the following service (formed by a different train) reported that they had passed through the section with no such issues. This difference in train performance, reported by two drivers 10 minutes apart, indicates that 57841 was apparently not managing the low adhesion as well as the following train. This could support that the automatic sanding system not functioning on vehicle 57841. Had the automatic sanding system been operational during this journey, the sand pipe blockage would probably have been cleared (paragraph 175). RAIB has not identified any other reported opportunities for the sand hoses of vehicle 57841 to become blocked between this journey and the collision.

Appendix E - The approach to adhesion management on Network Rail's Wales and Borders route

E1 The management of seasonal issues on the Wales and Borders route is described in a Joint Season Plan developed by Network Rail and TfWRL. Amey Infrastructure Wales is also involved but only in respect of the Core Valley lines in south Wales.

E2 Seasonal planning is divided into two parts. These are a 'summer' or warm weather period and a 'winter' or cold weather period. Arrangements for the autumn 'leaf fall' period are dealt with as part of the winter arrangements but preparations are made much earlier in the year.

E3 The 2024 Joint Season Plan, which covered the 2024 leaf fall season, including October 2024 when the accident occurred, was created by Network Rail's Wales and Borders route SDM and TfWRL's Head of Performance, assisted by TfWRL's Performance Improvement Manager. The Joint Season Plan is authorised by Network Rail's Route Director for Wales and TfWRL's Planning and Performance Director.

E4 The Joint Season Plan describes the SDM and TfWRL's performance improvement manager as the 'Seasonal Project Sponsors'. The Joint Season Plan contains milestones showing when certain aspects of the preparation should be completed. Before it is enacted, the detail of the plan is briefed to those with responsibilities for its delivery. Those involved in developing the plan explained that it was an evolution of arrangements from previous years, incorporating lessons learned from formal reviews. The SDM led the previous season's review and wrote a report outlining the changes from the 2023 season.

E5 Network Rail's SDM for Wales route had been in post since 2020 having previously worked as seasonal delivery specialist since 2015. The SDM role is a more strategic role, with the seasonal delivery specialist managing seasonal activities day to day and season to season. The SDM reported to the head of Readiness and Resilience, who in turn reported to the Operations Director for Wales and Borders route.

E6 Two groups are relevant to the enactment and supervision of seasonal plans. They are the Joint Seasonal Management Group (JSMG) and Joint Seasonal Steering Group (JSSG). Both meet every 4 weeks. JSMG deals with operational issues and approves the seasonal plans. It is attended by senior managers for Network Rail, TfWRL and Amey Infrastructure Wales. JSSG provides strategic oversight, and its attendees include Network Rail's Route Operations Director.

E7 For TfWRL, the main activities are ensuring that the stations it operates, its rolling stock, and its train crew, are prepared for the challenges of autumn and winter. One example of this is a consideration of TfWRL's capability to rectify wheel flats on trains caused by their operation in low adhesion conditions.

E8 For Network Rail, mitigations against low adhesion include:

- The provision and operation of RHTTs (paragraph 134).
- The use of TGAs (paragraph 279). While mostly used to aid traction in areas where trains experience low adhesion (such as significant uphill gradients), Network Rail occasionally uses them to assist braking in specific locations. The installation and maintenance of TGA equipment is set out in Network Rail standard NR/L3/TRK/3510/C01, 'Use of Traction Gel Applicators', issue 1 dated September 2011.
- The implementation of a seasonal control or 'Autumn Control desk' which operates for the duration of the leaf fall season at Cardiff Rail Operating Centre, which has a strategic overview of all rail operations in Wales, including those on the Cambrian lines. It is staffed by trained seasonal controllers, whose duties include receiving and collating reports of adhesion-related incidents such as reports of low adhesion from train drivers. They also manage the railway's response to adhesion-related matters such as occasions where RHTTs miss out planned treatment sites.
- ARTs are contracted by Network Rail for the leaf fall season. In Wales there are ten teams, based in five strategic locations; each location has a two shifts system covering from 0500 to 2200 every day. The teams based at Machynlleth generally cover Talerddig, as they are nearest to it. The ARTs are deployable by Network Rail to weather-related incidents such as reports of low adhesion by drivers. They have equipment that can be used to treat the railhead to improve adhesion, either by cleaning it or applying sand. ARTs also undertake proactive inspections of known sites of low adhesion, including Talerddig (paragraph 141).

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Any enquiries about this publication should be sent to:

RAIB
The Wharf
Stores Road
Derby UK
DE21 4BA

Email: enquiries@raib.gov.uk
Telephone: 01332 253 300
Website: www.raib.gov.uk