Rail Accident Investigation Branch

Rail Accident Report

Signal passed at danger and subsequent near miss at Didcot North junction 22 August 2007

Department for Transport

Report 23/2008
November 2008

This investigation was carried out in accordance with:

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

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Contents

Introduction

1 The sole purpose of a Rail Accident Investigation Branch (RAIB) investigation is to prevent future accidents and incidents and improve railway safety.

2 The RAIB does not establish blame, liability or carry out prosecutions.

3 Access was freely given by First Great Western (FGW) and Network Rail to their staff, data and records in connection with the investigation.

4 Appendices at the rear of this report contain the following glossaries:

- acronyms and abbreviations are explained in Appendix A; and
- technical terms (shown in *italics* the first time they appear in the report) are explained in Appendix B.

Summary of the Report

Key facts about the incident

5 At 16:38 hrs on 22 August 2007 train 1W47, the 15:51 hrs First Great Western passenger service from London Paddington to Worcester Shrub Hill, formed by a High Speed Train (HST) set, passed SB2209 signal at danger on the *Down Avoiding line* to the north of Didcot Parkway station. At the same time train 2P66, the 16:21 hrs First Great Western passenger service from Oxford to London Paddington, was just passing clear of the junction after being routed from the *Up Oxford line* towards Didcot Parkway station. Despite the correct operation of the *Train Protection Warning System* (TPWS) equipment, train 1W47 did not come to a stand until it had run onto the Up Oxford line, foul of the junction (Figure 1).

6 No injuries were incurred by any of the staff or passengers concerned. No damage was sustained by either train. However, had the circumstances been slightly different this event could have resulted in the two trains colliding.

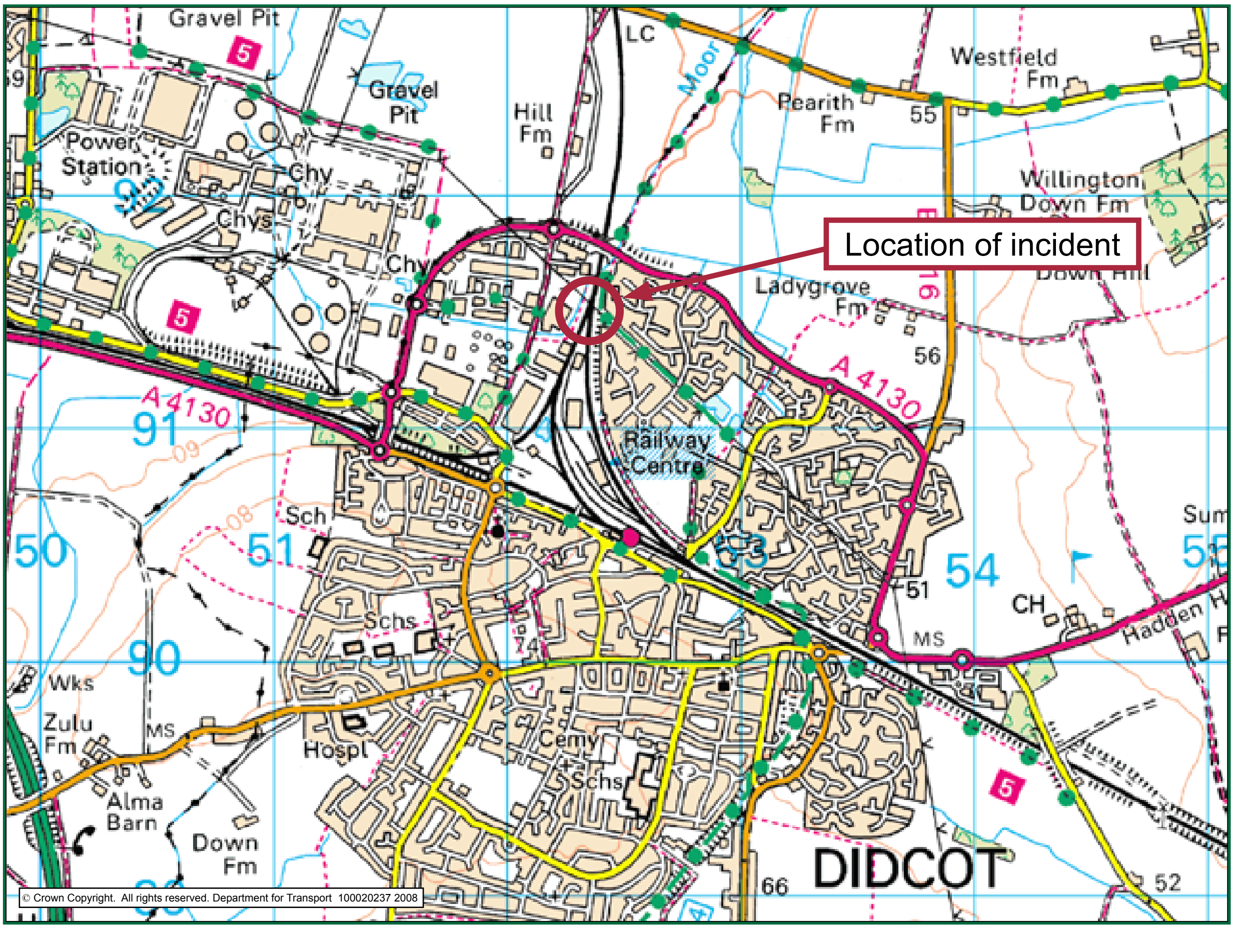

Figure 1: Extract from Ordnance Survey map showing location of incident

Immediate cause

7 Signal SB2209 was passed at danger because the driver did not respond correctly to the aspect of the previous (caution) signal, SB913.

Causal factors associated with signal SB2209 being passed at danger

8 Signal SB2209 was passed at danger because of the actions of the driver of train 1W47 on the approach to signal SB913. The most likely explanation for these actions is a combination of the following:

- the driver's expectation that the previous caution signal, SB913, would clear from yellow to a less *restrictive aspect*;
- the formation in his mind of an inappropriate mental model of the situation he was encountering;
- a loss of focus on the driving task leading to the driver not registering the aspect of signal SB913 on his approach; and
- the cancelling of two *Automatic Warning System* (AWS) warnings in quick succession without checking the aspect of the signal ahead.

Causal factors associated with the subsequent near-miss

9 The following factors are considered to have caused train 1W47 to stop foul of Didcot North junction, narrowly avoiding a collision with train 2P66:

a. the late identification of signal SB2209 at red due to external distractions; and

b. the braking performance of the HST set involved in the incident was below that assumed for the design of the TPWS at signal SB2209 although it exceeded that needed to comply with the *Railway Group Standards* for braking.

Contributory factors

10 The driver applied power to maintain the speed of his train in the expectation that the aspect would change. This driving behaviour is considered to have been a contributory factor.

Underlying factors

11 Network Rail had not yet installed enhanced TPWS equipment at this location following an earlier incident, despite there being a clear case for doing so following risk assessments that had been performed, and a recommendation by the investigation panel that this be done.

12 The local Recommendations Review Panel did not recognise the risk implications of the signalling arrangements at Didcot when considering the timescale for implementation of recommendations made following the *formal investigation* into the earlier incident.

Recommendations

13 The RAIB has made nine recommendations. These relate to the following areas:

- the conducting of risk assessments for junction signals, the methodologies for doing so and the implementation of any additional measures identified as necessary (three recommendations for implementation by Network Rail);
- the need for a review of standards for train braking performance and the dissemination of information on the braking performance of existing rolling stock (two recommendations for implementation by Rail Safety and Standards Board (RSSB)); and
- the development of driving policy and associated competence management systems (two recommendations for implementation by First Great Western and two for implementation by RSSB and the Association of Train Operating Companies (ATOC)).

The Incident

Summary of the incident

14 At 16:38 hrs on 22 August 2007 train 1W47, the 15:51 hrs First Great Western passenger service from London Paddington to Worcester Shrub Hill, formed by an HST set, passed SB2209 signal at danger on the Down Avoiding line to the north of Didcot Parkway station. This signal is located on the approach to Didcot North junction and is fitted with TPWS equipment that is designed to mitigate the consequences of signals being passed at danger.

15 At the same time train 2P66, the 16:21 hrs First Great Western passenger service from Oxford to London Paddington, was just passing clear of the junction after being routed from the Up Oxford line towards Didcot Parkway station. Despite the correct operation of the TPWS equipment, train 1W47 did not come to a stand until it had run onto the Up Oxford line, foul of the junction.

16 No injuries were incurred by any of the staff or passengers concerned. No damage was sustained by either train. However, had the circumstances been slightly different this event could have resulted in the two trains colliding.

17 Photographs of signal SB2209 and Didcot North junction are at Figures 2 and 3.

18 Diagrams of the railway lines in the area, and the associated track and signalling equipment, are at Figures 4 and 5.

Figure 2: Signal SB2209

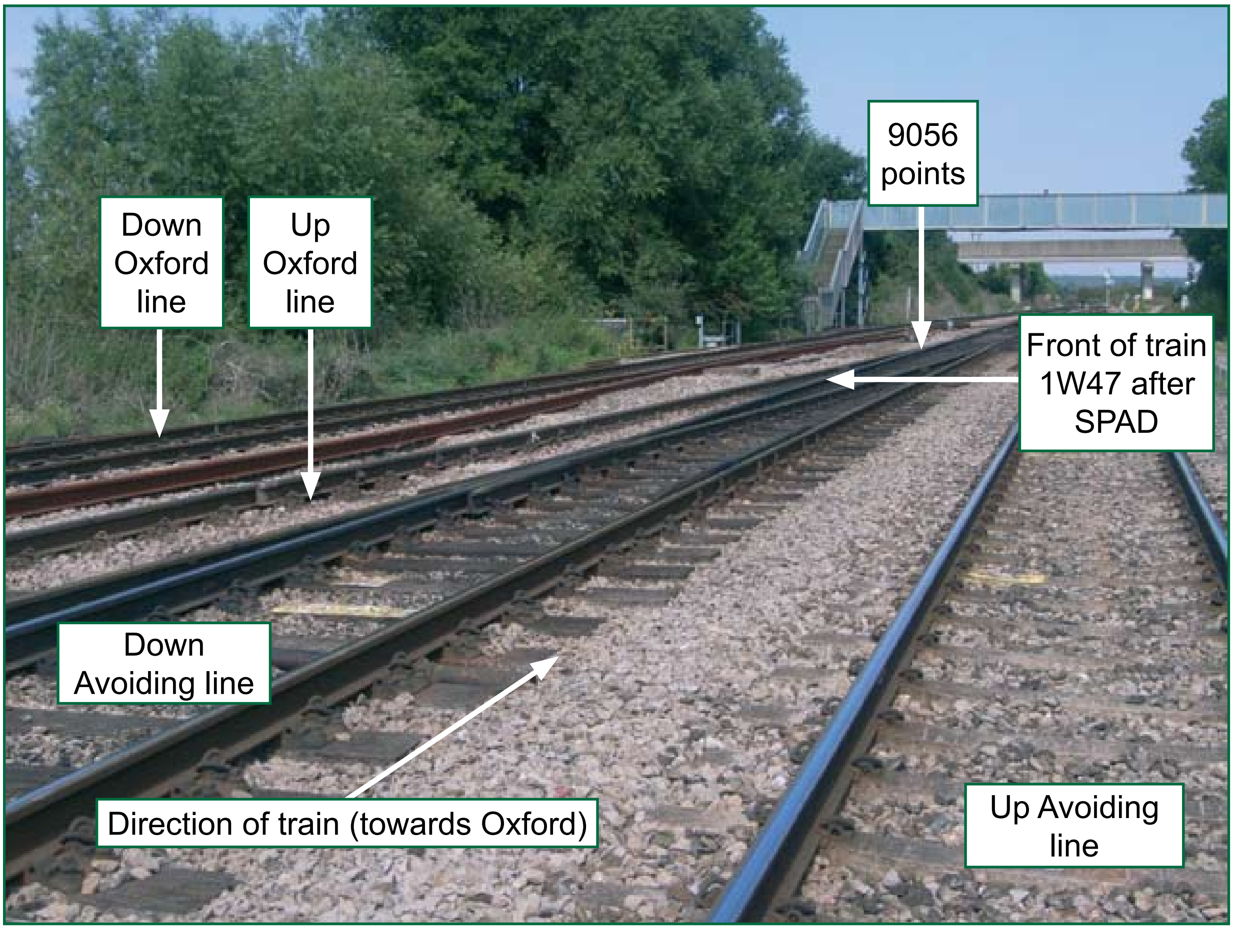

Figure 3: Didcot North junction

The parties involved

19 Both trains involved in the incident were operated by First Great Western.

20 The infrastructure is managed by Network Rail, which provides and controls the railway signalling equipment.

Location and routing of the trains involved

21 Didcot is located on the four track Great Western main line, 17 miles north-west of Reading. Didcot East junction is located about 350 m east of the station. At this junction the route to Oxford diverges from the Great Western main line and passes to the north of Didcot Parkway station before reaching Didcot North junction where the line converges with a line arriving from the direction of Didcot Parkway station and the west (Figure 4). This section of line between Didcot East and Didcot North junctions is known as the Avoiding line (since it 'avoids' Didcot Parkway station) and measures 1¼ miles (2 km) in length.

22 The signal that was passed at danger during this incident was located at the north end of the Down Avoiding line, 225 m south of Didcot North junction.

23 Trains from Oxford that require to call at Didcot Parkway station are routed via Didcot North junction, Didcot West Curve and Chester Line junctions to arrive at Didcot from the west.

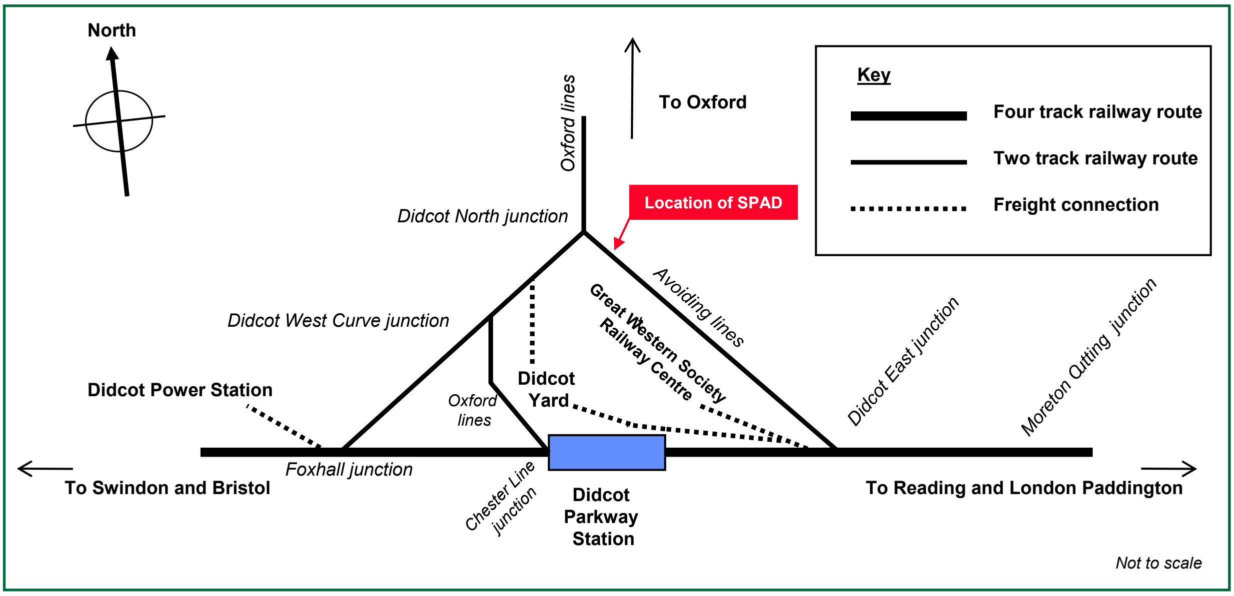

Figure 4: Railway lines in and around Didcot

24 Trains from the direction of Reading that are scheduled to travel via the Down Avoiding line can approach on the *Down Main* or *Down Relief line*. Those approaching on the Down Main line are required to divert onto the Down Relief line in order to reach Didcot East junction. To enable this move a series of crossovers is provided about 1¼ miles (2 km) east of Didcot at a location known as Moreton Cutting junction.

Track and signalling equipment

25 The maximum permitted speed for trains routed from the Down Main line towards Oxford is as follows:

• when traversing Moreton Cutting junction	70 mph (113 km/h)
• Down Relief line to Didcot East junction	70 mph (113 km/h)
• when traversing Didcot East junction	70 mph (113 km/h)
• on the Down Avoiding line	70 mph (113 km/h)

26 The maximum permitted speed for trains traversing Didcot North junction when routed from the Up Oxford line towards Didcot West Curve junction is 40 mph (64 km/h). At Didcot West Curve junction the maximum permitted speed for trains routed towards the station reduces to 25 mph (40 km/h).

27 The lines in and around Didcot Parkway station are signalled using track circuits and conventional line side signalling. Running signals on the main and relief lines east of Didcot are of the *four aspect* type. The remainder of the signals, including those on the Avoiding and Oxford lines, are of the *three aspect* type. The key characteristics of the signals involved in this incident are shown in Table 1.

28 These signals are controlled from the Swindon Signalling Control Centre. All of the route setting involved in the incident was commanded by the *Automatic Route Setting* system located at the Signalling Control Centre.

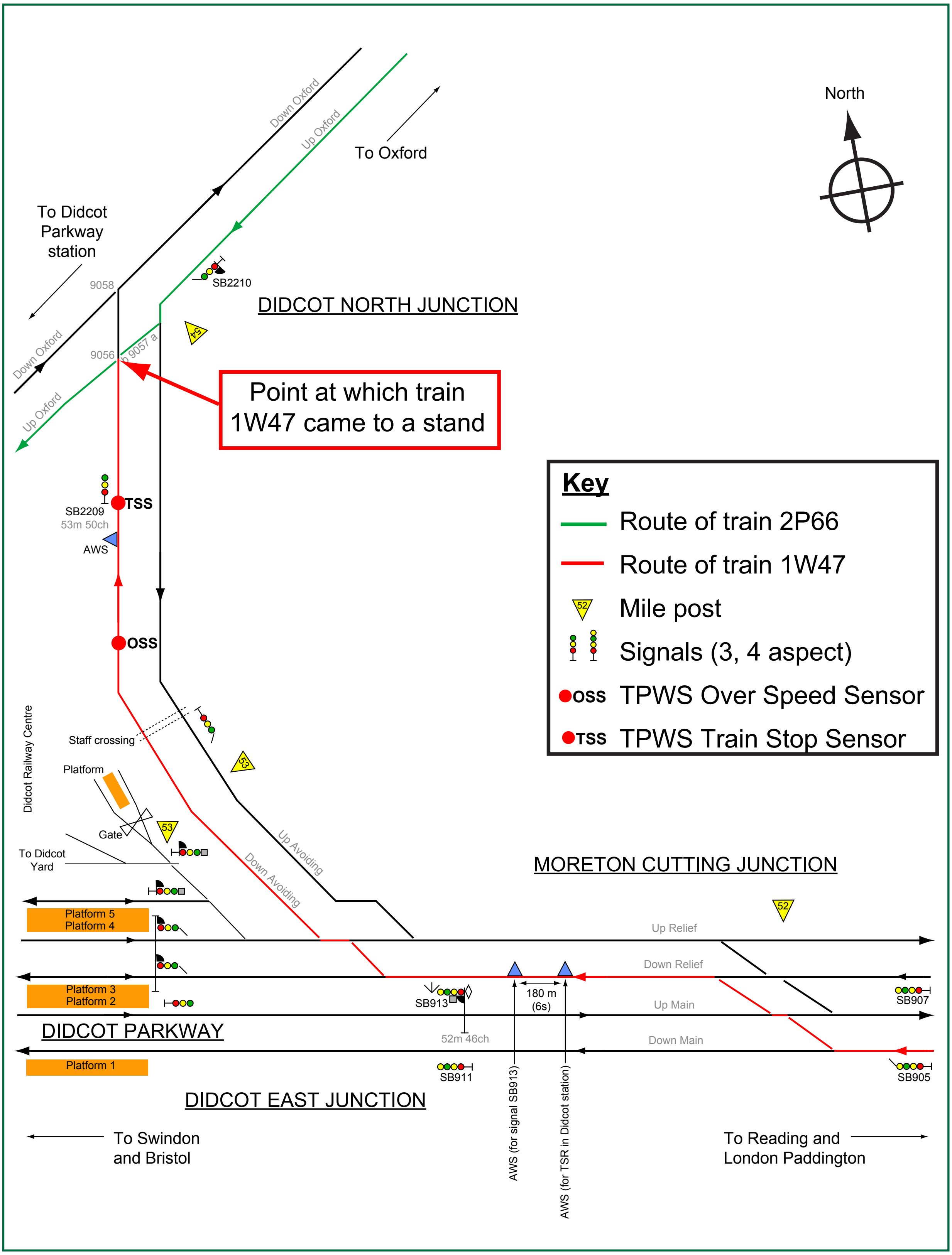

Figure 5: Layout of track and signalling equipment, and the routing of the trains involved in the incident

Route	Signals (listed in order encountered)	Location and function	Type	Train protection equipment associated with signal		
				AWS fitted?	**TPWS fitted?**	**ATP fitted?**
Down Main line to SB2209 (route of train 1W47)	DM48	Down Main line	four aspect, *automatic signal*	Yes	No	Yes
	DM49	Down Main line	four aspect, automatic signal	Yes	No	Yes
	SB901	Down Main line	four aspect, controlled signal	Yes	Yes	Yes
	SB905	Down Main line, junction signal for Moreton Cutting junction	four aspect, controlled signal, with *junction indicator (position 4)*	Yes	Yes	Yes
	SB913	Down Relief, junction signal for Didcot East junction	four aspect, controlled signal, with junction indicators (positions 4, 5 and 6)	Yes	Yes	No
	SB2209	Down Avoiding line, protecting signal for Didcot North junction	three aspect, controlled signal	Yes	Yes	No
Up Oxford line towards Didcot West Curve junction (route of train 2P66)	SB2214	Up Oxford line	three aspect, controlled signal	Yes	Yes	No
	SB2210	Up Oxford line, junction signal for Didcot North junction	three aspect, controlled signal, with junction indicator (position 4)	Yes	Yes	No

Table 1: Listing of signalling equipment (see also Figure 5)

29 On the approach to each of the signals listed in Table 1 are AWS magnets. If the associated signal is showing a restrictive aspect (i.e. double yellow, yellow or red), when the train passes over the AWS magnets, an audible warning (a horn) is sounded in the cab and a black AWS visual indication is displayed. Once the driver has reset the AWS by pressing a button on his control panel the indication changes to black and yellow (this display is known as the 'sun-flower'). This acts as a reminder to the driver that the signal ahead is showing a restrictive aspect. If the driver does not cancel an AWS warning within a short time (1.9 or 3 seconds, depending on the type of train) the emergency brakes will apply to stop the train.

30 If the signal is green, a different and distinct signal (a bell) is sounded and no warning indication is displayed.

31 At the time of the incident, on the approach to signal SB913 there were located two AWS magnets. The first, located about 360 m from the signal, provided a warning to drivers of trains routed towards Didcot Parkway station of a temporary speed restriction ahead. This speed restriction did not apply to trains routed via the Down Avoiding line, but the presence of the magnet would nevertheless cause an AWS warning to activate in their cabs.

32 The AWS magnet associated with signal SB913 was located 180 m beyond the magnet associated with the temporary speed restriction. The presence of both magnets resulted in the drivers of trains approaching a restrictive aspect on signal SB913 receiving two warnings in quick succession.

33 All of the controlled signals listed in Table 1 were fitted with TPWS equipment.

34 When used in association with signals, TPWS is designed to intervene if it detects that a train has passed a signal that is at danger. At some signals there is also a means of detecting that a train is approaching at too high a speed to be able to stop at the signal.

35 In both the above cases TPWS will intervene by initiating an emergency brake application on the train, causing it to stop. In the case of signals protecting junctions, the design intent of the system is to mitigate the consequences of a signal being passed at danger by stopping trains before they foul the junction ahead[1] or, if this is not practicable due to an insufficient distance beyond the signal, to reduce its speed of approach.

36 The above functionality is achieved by equipment fitted to the train which is activated by the following track side equipment:

- a *train stop* sensor located between the rails at, or close to, the signal; and
- an *over-speed sensor*, located between the rails on the approach to the signal.

37 The train stop sensor is designed to trigger an emergency brake application if a train passes over it when the associated signal is showing a red aspect. The over-speed sensor is designed to trigger an emergency brake application if the train is approaching a red signal at an excessive speed. More details of each type of sensor are provided at paragraph 136.

38 Figure 6 illustrates the track layout, the arrangement of signalling equipment, TPWS and key dimensions in the immediate area of signal SB2209. Important distances and speeds are shown in Table 2.

Sighting distance of signal SB2209	400 m
Distance between over speed sensor *arming* and *trigger loops*	18.4 m
Distance between over speed sensor trigger loop and signal SB2209	275 m
Speed at which the over speed sensor would cause the emergency brakes of a passenger train to apply	41.5 mph (67 km/h)
Distance between signal SB2209 and fouling point	201m

Table 2: Signalling and TPWS on the approach to signal SB2209, key values

39 Paragraphs 135 to 147 provide more detail of the above equipment.

[1] The point at which a train fouls a junction is known as the 'collision point' or 'fouling point'. The term 'fouling point' is used throughout this report.

40 The signals on the Down Main line were fitted with a form of *Automatic Train Protection* equipment. This equipment provided to the driver (of any train equipped to interface with this system) a visual indication of the permitted speed, and a target speed when the driver is required to reduce speed[2]. This equipment also monitored the speed of the train and would intervene, by causing the brakes to apply, should the driver fail to respond correctly to speed restrictions or signal aspects ahead.

41 The extent of provision of Automatic Train Protection equipment did not include signals on the Down Relief or Down Avoiding lines. For trains fitted with Automatic Train Protection this caused the in-cab display to disappear as they traversed Moreton Cutting junction.

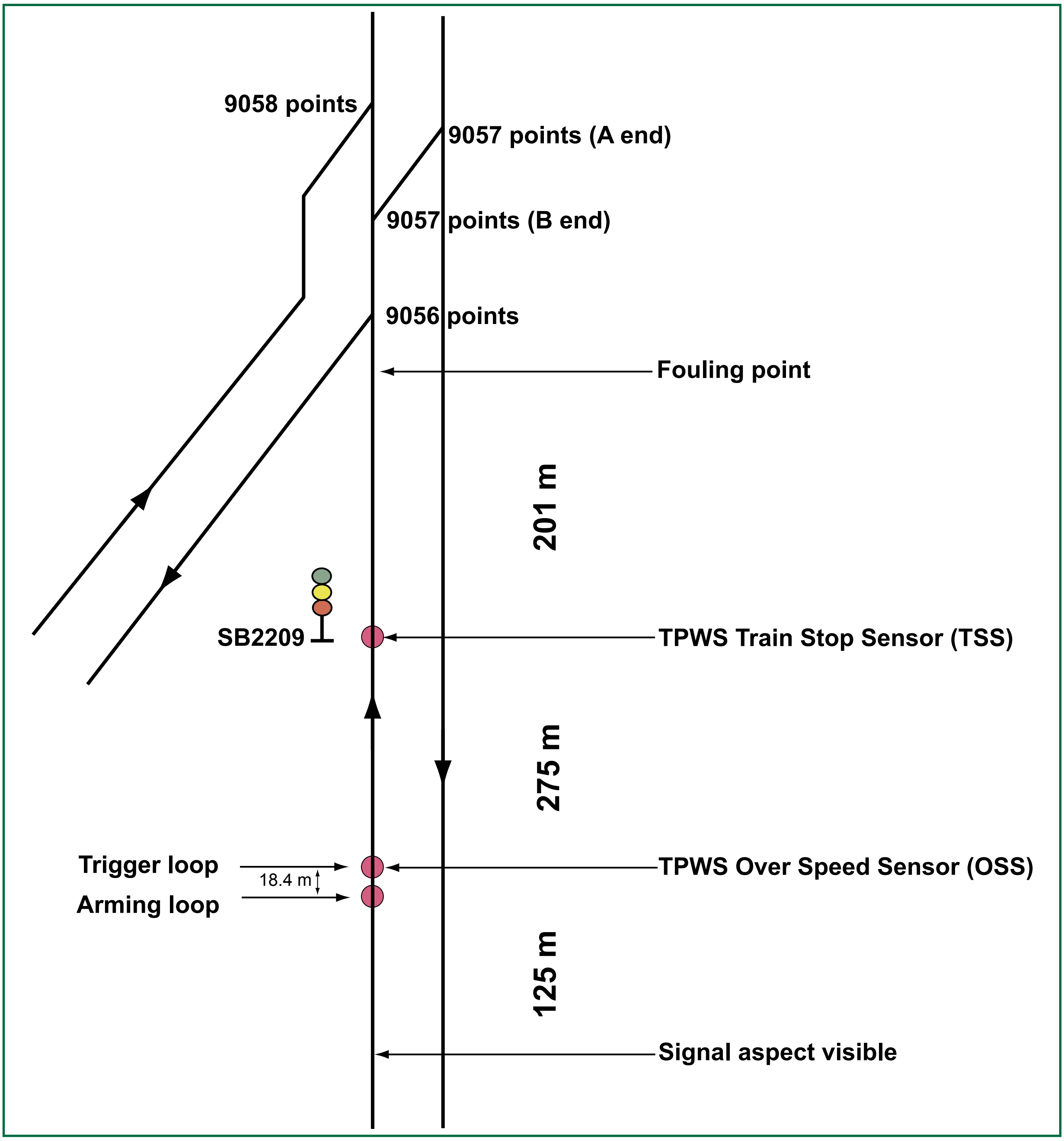

Figure 6: Track layout, the arrangement of signalling equipment, TPWS and key dimensions in the immediate proximity of signal SB2209

[2] This speed is calculated by the ATP system taking into account the maximum permitted speed for the line concerned, any temporary speed restrictions and the aspect of the signal ahead.

Trains

42 The train that passed signal SB2209 at danger, 1W47, was formed by HST set LA72. This set was made up as follows:

- power car 43128 (leading);
- eight coaches; and
- power car 43172 (trailing).

43 Set LA72 measured 224 m in length and was permitted to operate at speeds of up to 125 mph (201 km/h). In common with all HST sets, LA72 was fitted with an electrically controlled air brake system. This works by translating a driver's brake command into electrical signals that are transmitted via the *train lines* to cause the opening of electrically controlled pneumatic valves located in each power car. Brake force is applied to the wheels on the trailer vehicles by means of discs and pads. Wheels on the power cars are braked by a combination of disc and tread brakes.

44 The brake controller provides the driver with six normal steps. Step 1 applies the lowest brake force and step 6 the maximum (known as full service braking). Emergency braking can also be applied through the brake controller or by striking a plunger on the desk[3].

45 The power controller provides the driver with five normal steps (each step is known as a 'notch'). Notch 1 applies the lowest amount of power and notch 5 the maximum.

46 Set LA72 was fitted with AWS, TPWS and Automatic Train Protection equipment.

47 The train that passed across Didcot North junction just before signal SB2209 was passed at danger, 2P66, was formed of 5 vehicles consisting of 2-car class 165 and 3-car 166 diesel multiple units.

48 The total length of train 2P66 was 117.5 m.

External circumstances

49 The weather was overcast and windy, but dry. Visibility was good with no bright sunshine. There is no evidence of any light conditions or other environmental conditions affecting the visibility and clarity of signal aspects.

50 At the time of the incident there was activity in the Great Western Society centre at the south side of the Avoiding lines (Figure 4). This included the operation of at least one steam locomotive.

[3] Step 6 (full service) and emergency braking will ultimately provide the same level of brake force. However, the application of the emergency brake will result in the brakes taking full effect more quickly.

Sequence of events

The journey of train 1W47 from Paddington to signal DM49

51 The train left Paddington at its scheduled time. The train was then scheduled to call at Slough.

52 Data obtained from the on-train data recorder (OTDR) shows that the driver's approach to Slough involved the application of full service brake for a period of 20 seconds within half a mile (0.8 km) of the station. This application of full service brake caused a near constant deceleration of about 10.6 %*g*.

53 After the stop at Slough the train continued to Reading. On the approach to Reading the train incurred a slight delay due to a train occupying the platform ahead.

54 The train left Reading three minutes behind schedule and continued towards Didcot on the Down Main line, without incident. When the train was about 4 miles (6.5 km) east of Didcot the driver observed a double flashing yellow aspect on signal DM49. This was an indication that the route was set across the junction at Moreton Cutting, 2½ miles (4 km) ahead. On seeing this, the driver shut-off power in order to reduce speed in preparation for the junction ahead. At this point the train was running about 1½ minutes behind schedule.

The journey of train 1W47 from signal DM49 to Didcot North junction

55 Train 1W47 was routed from the Down Main line onto the Down Relief line via a series of crossovers at Moreton Cutting junction. It was then routed onto the Down Avoiding line, via facing points at Didcot East junction, towards the signal protecting Didcot North junction, SB2209. The aspects displayed to the driver on the relevant signals were as shown in Table 3.

Signal	**Aspect displayed to train 1W47**	**Meaning**
DM49	double flashing yellow	diverging route set at Moreton Cutting junction, reduce speed of train (speed of junction is 70 mph), next signal is showing a single flashing yellow aspect
SB901	single flashing yellow	diverging route set at Moreton Cutting junction, reduce speed of train (speed of junction is 70 mph), next signal is showing a yellow aspect
SB905	single yellow + position 4 junction indicator (not seen by driver) *approach released* to	diverging route is set to right (i.e. across junction, onto Down Relief); be prepared to stop at next signal (SB913)
	double yellow + position 4 junction indicator	diverging route is set to right (i.e. across junction, onto Down Relief); be prepared to find the next signal (SB913) displaying one yellow aspect
SB913	single yellow + position 6 junction indicator	diverging route is set to right onto the Down Avoiding line; be prepared to stop at next signal (SB2209)
SB2209	red	stop/danger

Table 3: Signal aspects displayed on the approach of train 1W47

56 Throughout the journey between SB905 and the point at which TPWS intervened, train 1W47 was driven at or close to 70 mph (113 km/h), the maximum permitted for the routes concerned. When braking for Moreton Cutting junction the driver used only step 1 and step 2 braking thereby achieving a modest deceleration of around 5 %g and arriving at the junction at a speed very close to that permitted, 70 mph (113 km/h). The driver then held the speed of the train close to 70 mph (113 km/h) for the remainder of the journey along the Down Relief and Avoiding lines. He did this by keeping the brake in the off position and applying notch 1 power.

57 Just before the train reached the over-speed sensor (located 275 m before signal SB2209) the driver saw that signal SB2209 was displaying a red aspect. However, before he responded, the TPWS intervened by applying the emergency brake.

58 The train passed signal SB2209 at 53.5 mph (86 km/h) and stopped about 12 m beyond the crossing of 9056 points, foul of Didcot North junction (at the location marked on Figure 3).

59 More detail of the sequence of events is at Appendix C.

60 Appendix D contains an overview diagram showing all of the signals and the routing of the trains involved in the incident.

Consequences of the incident

61 As train 2P66 passed the signal protecting Didcot North junction, SB2210, it was displaying a green aspect (+ junction indicator).

62 The front of train 2P66 passed signal SB2210 30 seconds before train 1W47 passed signal SB2209 at danger. As the front cab of his train was passing over 9056 points at Didcot North junction the driver of train 2P66 could see train 1W47 approaching the junction from his left. He continued to drive his train towards Didcot Parkway station to clear the junction.

63 Analysis of OTDR and signalling data (in particular the times of occupation and release of track circuits) has enabled the RAIB to calculate that the time that elapsed between the back of train 2P66 clearing the fouling point of 9056 points at Didcot North junction and train 1W47 reaching the fouling point was 13 seconds (see Appendix C).

Events following the incident

64 The passing of signal SB2209 caused the sounding of an alarm in Swindon Signalling Control Centre which alerted the signaller. The signaller responded by immediately requesting the control office to transmit an emergency call to trains in the area by means of the *National Radio Network* equipment. This was promptly carried out as requested.

65 Poor radio reception impeded the initial conversation between the signaller and driver of train 1W47. For this reason the signaller requested that the driver contact him again by means of the telephone.

66 The driver walked back to signal SB2209 and contacted the signaller by means of the telephone on the signal post. The signaller led the conversation by asking a series of questions. In his responses the driver acknowledged that he had passed signal SB2209 at danger due to his own error. However, he was unable to give any reason other than a loss of concentration. The driver also stated that he had been aware that signal SB913 had been showing a yellow aspect.

67 The train was subsequently reversed behind signal SB2209 to clear the junction.

68 The train was driven to Oxford by the driver, accompanied by a Train Crew Manager, where it was terminated and the passengers were disembarked.

The Investigation

Investigation process

69 The Network Rail National Operations Centre judged that a near-miss had occurred that was notifiable to the RAIB in accordance with Schedule 1(9) of the Railways (Accident Investigation and Reporting) Regulations 2005. The RAIB immediately deployed two inspectors to the site and began a preliminary examination of the incident.

Sources of evidence

70 The main sources of evidence used in this investigation were:

- witness interviews;
- discussions with engineers and managers;
- cab rides and discussions with train drivers;
- data derived from the OTDR system;
- signalling data;
- voice recordings;
- photographs and measurements from a visit to the site;
- review of appropriate standards and guidance notes;
- review of operating documentation; and
- other documents and reports.

Key Information

Previous occurrences of a similar character

71 There have been three previous recorded incidents in which signal SB2209 was passed at danger. These occurred on 22 November 1994, 19 May 1996 and 24 March 2004.

72 All three incidents involved class 165 and/or 166 diesel multiple units. The cause of the first two incidents is recorded as being the driver not responding correctly to the signal aspects that were being displayed. In the second of the incidents the length of the overrun beyond signal SB2209 was recorded as being 500 m (i.e. foul of Didcot North Junction).

73 The incident that occurred on 24 March 2004 involved train 1D08, a 6 car class 166/165 diesel multiple unit, operated by Thames Trains[4], that had been routed from the Down Relief onto the Down Avoiding line. Train 1D08 passed SB913, which was displaying a yellow aspect, at close to 70 mph (113 km/h) and continued towards signal SB2209 without reducing speed significantly. The train was travelling at 68 mph when the driver observed that signal SB2209 was displaying a danger aspect. He made an emergency brake application approximately 350 m from the signal and the train came to a stand with the front cab 30 m beyond the signal (i.e. well clear of the fouling point).

74 A ‘formal investigation’ by Network Rail and Thames Trains was initiated following the incident on 24 March 2004. It concluded that the driver had failed to respond correctly to the yellow aspect at signal SB913 but had instead driven in a manner commensurate with his believing that signal SB913 was showing a green aspect. Furthermore, the investigation report identified a possibility that the driver had lapsed into an ‘automatic’ mode and was focusing on one element of the driving task rather the whole.

75 The recommendations of the formal investigation report are summarised below:

1. Thames Trains to carry out an assessment of the driver’s performance against the requirements of the company’s Driver Manual.
2. Network Rail to clear vegetation adjacent to the Up Avoiding line in order to improve sighting of signal SB2209.
3. Network Rail’s signaller to be debriefed and assessed on the procedures to be adopted if a driver makes an allegation of a signalling failure.
4. Network Rail to provide a supplementary TPWS over-speed sensor on the approach to signal SB2209 to ensure that an errant train stops before reaching the fouling point.

76 The last of the above recommendations was based on the opinion of the investigation team that there was a ‘high probability that the signal would be passed at danger in the next 10 years’. This opinion was informed by a review of the previous incidents and the output of a quantified risk assessment using Network Rail’s Signal Assessment Tool (SAT). Details of the SAT assessment are covered in more detail at paragraphs 160 to 167.

<u>Management of the recommendations following the incident on 24 March 2004</u>

77 The recommendations in the report of the above investigation that were relevant to Network Rail were reviewed by the local Recommendations Review Panel covering the Western Route on 21 September 2004. This panel consisted of operations, safety, maintenance and signalling professionals.

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[4] The train services previously operated by Thames Trains were transferred to First Great Western in 2006 as part of a franchise change.

78 During that meeting the Recommendations Review Panel had a large number of issues to review. This included consideration of twenty two new recommendations directed at Network Rail (from eight investigations).

79 Three of the twenty two new recommendations that were reviewed were those directed at Network Rail following the incident on 24 March 2004. Recommendation 2 (vegetation clearance[5]) was rejected by the Recommendations Review Panel on the grounds that the sighting of signal SB2209 was already adequate and compliant with the standard. Recommendation 3 (re-briefing and assessment of the signaller) was endorsed for implementation within eight weeks. Recommendation 4 (provision of a supplementary over-speed sensor) was endorsed for implementation within three years. This timescale reflected the panel's assessment that the risk associated with this signal was 'low'. This decision was made despite an assessment in the investigation report that the probability of a recurrence within ten years was 'high' and without detailed reference to the risk assessment that had already been carried out using the SAT.

80 Three years later, in March 2007, the Western Route's Recommendations Review Panel accepted an application from the Territory Signal Engineer that the provision of the supplementary over-speed sensor be delayed until March 2009 because there was limited resources to design and deliver the work. This application was accepted by the panel, and the target date for implementation was revised accordingly, without further reference to the risk assessment.

Signals passed at danger - background

81 The railway industry uses the term 'Signal Passed at Danger' (SPAD) to describe an incident during which a train passes (without authority) a signal that is displaying a stop/danger aspect.

82 When a SPAD occurs the safety impact can be significant. Potential consequences include collision, derailment and/or major disruption to the operation of trains. Consequently, a range of measures have been progressively introduced that have mitigated the risks associated with SPADs. These include:

- the introduction of colour light signalling (commencing in the 1930s);
- the introduction of AWS (the first main line example was introduced by the Great Western Railway from 1906 onwards; AWS in its current form was installed by British Railways from the mid-1950's);
- improved train braking;
- driver training and education; and
- systematic procedures for reporting and investigation.

83 SPADs remained a significant precursor of train accidents until the late 1990s. Public concern about the risk was heightened by two serious collisions that were caused by signals being passed at danger, at Southall in September 1997 and Ladbroke Grove in October 1999.

[5] This recommendation reflected an earlier recommendation made by the Signal Sighting Committee following a post-incident site visit on the 23 April 2004.

84 By the time of the collision at Ladbroke Grove, detailed development and testing of a new system, TPWS, was already ongoing, although the extent of its installation had still to be decided.

85 Full-scale installation of TPWS at numerous junctions and high risk locations commenced in 2001 and was completed in the early part of 2004. Since the installation of TPWS there has been a 22 % reduction in the number of SPADs and an estimated 86 % reduction in the overall risk (see Figure 7). This reduction is due in large part to the installation of TPWS but also reflects factors such as driver management, improved train performance and crashworthiness.

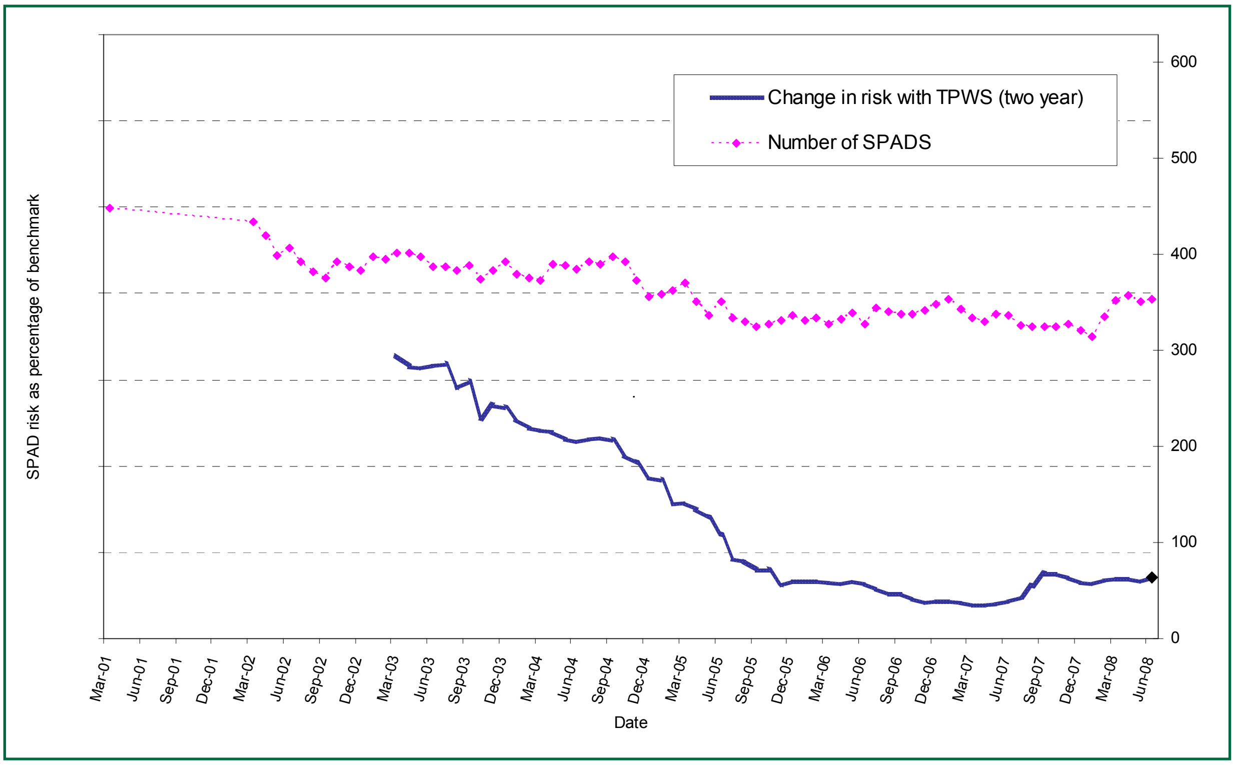

Figure 7: Change in SPAD risk over time

The driving of train 1W47

The driver

86 The driver involved in the incident was based at First Great Western's depot at Bristol and had been qualified to drive trains since 1972. He transferred to Bristol depot in 1983 and became qualified in that year to drive HSTs.

87 During the driver's career he had never before driven past a signal at danger without authorisation. However, in 2006 he was involved on two separate incidents on the Cotswold line. In the first he overran Charlbury station after reportedly misjudging the braking. In the second he triggered a TPWS over-speed sensor intervention due to excessive speed on the approach to a signal at Moreton-in-Marsh. Following this second incident First Great Western identified a need to enhance its monitoring of the driver's performance. This reflected a concern that the recent incidents were evidence that the driver had not been driving in the '*defensive*' manner outlined in the First Great Western driving policy.

The driver's competence and training

88 At the time of the incident the driver was qualified to drive the following types of traction:

- HSTs (class 43); and
- class 08 (shunting locomotive).

89 The driver's ongoing competence is assessed as part of a two year cycle. The last cycle ended in January 2007. This had incorporated each of the following methods of assessment:

- direct observation by Driver Managers (on five occasions encompassing more than seven hours of driving time);
- review of OTDR data (on two occasions encompassing more than four hours of driving time);
- questions and answers (verbal or written); and
- written tests.

90 No substantive issues were identified in any of the direct observations of the driver's performance. Most remarked on the driver's professional driving style and good management of the driving controls and brakes.

91 In March 2006 the driver was assessed for his knowledge of:

- the rule book;
- HST and class 08 traction knowledge;
- personal track safety; and
- fire training.

92 The assessments took the form of written and computer based tests. He was successful in all assessments, scoring 109 out of 120 in the rules exam (none of his wrong answers are relevant to the circumstances of the incident on 22 August 2007).

93 A review of OTDR data that was carried out on the 10 August 2006 identified two areas for review. One of these was associated with the testing of brakes and the other with the testing of the Drivers Safety Device.

The driver's route knowledge

94 Drivers based at Bristol depot were rostered to work duties laid out in a number of roster patterns (known as links). Two of these links included train driving duties via the Didcot Avoiding line. Each was designed to rotate turns of duty between all of the drivers within the link, over a period of 40 weeks, in order that the types of work and hours of duty were fairly spread, while providing sufficient periods of rest to avoid drivers becoming fatigued.

95 Drivers allocated to these links are required to drive over a wide range of routes. Some routes, for example Bristol to Paddington, are a regular feature of the drivers' duties. However, other routes such as Worcester to Oxford are driven over less frequently.

96 The driver who was involved in the incident on 22 August 2007 had been rostered to drive via the Didcot Avoiding line on three occasions every 40 weeks. Drivers on the other link were rostered to drive via the Didcot Avoiding line on two occasions every 40 weeks. However, both rosters were subject to short term alterations to cover operating contingencies, leave, sickness and the authorised exchange of duties between drivers.

97 As a consequence of the above factors, the driver had previously driven via the Down Avoiding line at Didcot on only five occasions since August 2005 (he had also driven from Didcot East junction to Didcot North junction via the station on four occasions). In this two year period there were two intervals of about seven months during which the driver did not drive via the Down Avoiding line.

98 The driver kept records of which routes he had driven over. Consequently, he identified that his route knowledge was lapsing and had requested, and was granted, opportunities to refresh the route by watching a route learning DVD in the training school. Such 'route refresher' training had taken place on four occasions since August 2005.

99 The combination of driving and refresher training meant that the driver had experienced the Didcot Down Avoiding line on nine occasions in the two years prior to 22 August 2007. This represents an average of one exposure to the route every 11.6 weeks. This is greater than the minimum exposure of once every 8.7 weeks (three instances in 26 weeks) that is specified in First Great Western's company standard (see paragraph 114).

100 During the two years prior to 22 August 2007 there was one period of five months, and another of four months, when the driver had not been exposed to the route via the Down Avoiding line.

101 Despite limited exposure to the route in recent years, the driver demonstrated to the RAIB a good knowledge of the track layout and signalling arrangements.

The driver's actions and influencing factors

102 Paragraphs 51 to 59 and Appendix C describe the actions of the driver of train 1W47. Of particular note are the following:

- the unusually heavy brake application on the approach to the station at Slough;
- the application of power having passed signal SB905 at double yellow and after seeing signal SB913 at yellow; and
- continued driving at a speed close to the maximum permitted (signal SB913 was still showing a yellow aspect when passed at a speed of 68 mph).

103 There is no evidence of any personal factors or work pressures that are likely to have influenced the behaviour of the driver on the journey from Paddington to Didcot. The driver was rested having slept normally the night before. The previous day the driver had not driven trains but was engaged on duties in connection with the management of the depot.

104 The HSE *fatigue index* was used to identify if work related shift patterns had been a cause of fatigue[6]. A low score of 1.4 confirms that this was not the case.

105 On 22 August 2007 the driver had booked on at Bristol at 12:50 hrs and travelled as a passenger to Paddington. He arrived at 14:45 hrs and took his scheduled break in the mess room, then left to prepare the set that was to form the train 1W47. There is no evidence that the driver had become stressed or distracted at this stage or at any point in the subsequent journey.

[6] The potential for fatigue arising from the above work pattern has been assessed using the Health and Safety Executive (HSE) Fatigue and Risk Index Calculator (version 2.2) available from www.hse.gov.uk. The output from the Fatigue Index (FI) is a measure of the probability of high levels of sleepiness. This is expressed as a value of between 0 and 100. A FI of 20.7 corresponds to the average work shift and rest pattern, assuming typical values for the job type and breaks factor.

106 OTDR data shows that on the approach to Moreton Cutting junction the driver braked his train such as to arrive at the first crossover at exactly 70 mph (113 km/h). Having traversed Moreton Cutting junction, he applied power in order to maintain his speed very close to 70 mph (113 km/h) up to the point where the TPWS intervened on the approach to signal SB2209.

107 There is evidence that the driver saw that signal SB913 was yellow as he traversed Moreton Cutting junction. Nevertheless, despite being aware that SB913 was displaying a yellow, the driver applied power, at notch 1 to maintain speed on the approach to Didcot East junction.

108 OTDR data indicates that the AWS magnet for signal SB913 operated correctly and was acknowledged by the driver within less than a second. However, this acknowledgement came only 6 seconds after he had acknowledged the AWS warning associated with a temporary speed restriction in Didcot Parkway station (paragraphs 31 and 32).

Driving guidance and policy

Association of Train Operating Companies (ATOC) guidance

109 A guidance note issued by the Rail Safety & Standards Board (RSSB) on behalf of ATOC provides advice to train operators on the inclusion of defensive driving techniques in train operators' professional driving policies. This note (ATOC/GN007) states that when approaching restrictive aspects (such as a yellow) drivers should take appropriate action according to the operating conditions. These are described as follows:

- planning ahead; this may involve shutting off power, coasting or applying the brake;
- a driver should never 'chase' signals showing restrictive aspects, i.e. never assume that a signal showing a restrictive aspect will clear to a less restrictive aspect on approach; and
- a driver should always be mindful of the risks of inattention, especially when running on successive signals showing restrictive aspects.

First Great Western driving policy

110 First Great Western policy on the driving of trains is summarised in a booklet issued to all drivers. This booklet, entitled 'Professional Driving and Driving Standards', was issued in October 2003. This booklet includes a description of the First Great Western policy on the application of brakes. In particular it states:

> 'When applying the brake on the approach to any preliminary caution or caution signals, concentration is vital at all times. Don't become distracted.'

111 In guidance on how to achieve this, it states:

> 'Under normal conditions (with standard signal spacing, good railhead conditions and when travelling at or near line speed), having the brake in an applied position BEFORE reaching the AWS magnet of the first cautionary signal is seen as good practice.'

112 A further element of the policy entitled 'consistency of brake applications' includes text on the AWS. This states:

> 'Always be mindful of the risks of repeated cancelling of the AWS. This can lead to semi-automated responses. This in turn may lead to the AWS warning horn losing its normal "impact" as an in-cab audible warning device.'

113 This section of the policy also includes guidance on responding to signal aspects. This states:

> 'Do not "chase" signal aspects expecting them to clear in front of you. Hold back to give an extra safety margin. NEVER adopt this technique for red signal aspects.'
>
> and
>
> 'When cautionary signal aspects are clearing to a less restrictive aspect on your approach, adjust your speed accordingly. Try to avoid repetitive acceleration and braking.'
>
> and
>
> 'Never expect a signal to clear as you approach it.'

First Great Western policy on the retention of route knowledge

114 At the time of the incident the relevant Railway Group Standard (RGS), GO/RT3251, mandated that train operators carry out a risk assessment of each route as an input to the arrangements for the retention of route knowledge. In response to this requirement First Great Western carried out an assessment of the minimum programmed work for a driver to retain route knowledge over all of its routes. This assessment concluded that the minimum required between Didcot and Oxford is three instances in every 26 weeks (equivalent to an average of once every 8.7 weeks). However, there is no separate requirement for the number of instances via the Didcot Avoiding lines. This is because First Great Western does not believe that the Avoiding lines are a distinct route and argue that any driver familiar with the main line route, and the route to Oxford via the station, will have gained sufficient geographic knowledge of the area.

115 There is no standard or industry research to support the adequacy of the above retention requirements. However, a recent study carried out by Air Affairs (UK) Ltd, on behalf of RSSB[7], identified that a driver's route knowledge will strongly influence his awareness of the situation he is encountering and his ability to react in an appropriate manner.

116 First Great Western record the route knowledge of drivers on a computer manpower planning system. However, the way in which this system was used did not permit First Great Western to systematically track and record the number of times that each driver had been exposed to each section of line.

117 First Great Western driving policy stated that drivers should maintain a record of the turns they had undertaken and sign a card recording their route knowledge on an annual basis. Drivers were generally aware that they should notify management if they were in need of refresher turns. However, there was no clear guidance on the steps to be taken if the company's route retention requirements were not met.

SPADs, First Great Western performance

118 Data on SPADs, across the UK network, is collated, analysed and published by RSSB. To allow comparison between different train operators RSSB normalise the number of recorded SPADs. This is done by calculating, for each train operator, the number of SPADs per 100 drivers employed. An alternative measure is the number of SPADs per million train miles operated by each train operator.

[7] Route Knowledge Study (Project T150), 23 January 2006, RSSB.

119 Table 4 shows the First Great Western 'SPAD rates' calculated by the RSSB using both of the methods of normalisation described above. This shows that the First Great Western 'SPAD rate per 100 drivers' was well below the national average in 2004 and 2005. In April 2006 the former Thames and part of the former Wessex Trains franchises became part of the Great Western franchise. In this same year the First Great Western 'SPAD rate' increased by a third and was now at a level above the national average. The year 2007 saw a further increase in the SPAD rate to a level more than twice that for 2005.

120 The 'SPAD rate per million train miles' was well below the national average from 2004 to 2006. The year 2007 saw an increase in the SPAD rate to a level nearly three times that for 2005.

121 Data published by RSSB indicates a significant reduction in the First Great Western SPAD rates during the first half of 2008.

Year	**Number of SPADs** (per 100 drivers employed)				**Number of SPADs** (per million train miles operated)		Notes
	First Great Western	Wessex Trains	Thames Trains	National average (for all train operating companies)	First Great Western	National average (for all train operating companies)	
2004	1.35	2.76	2.64	1.77	0.54	1.01	
2005	1.38	Not available	Not available	1.83	0.36	0.96	
2006	1.92			1.73	0.55	0.96	Thames Trains and part of the Wessex Trains became part of the Great Western franchise in April 2006.
2007	2.82			1.83	0.94	0.92	

Table 4: Comparison of 'SPAD' rates

Train braking performance

Standards

122 The braking performances required for trains to be authorised to operate on the national network are defined in a series of Railway Group Standards. These include the maximum permissible distance to stop over the normal range of operating speeds and the recommended minimum stopping distances to reduce the possibility of wheel tread damage caused by wheel slide during braking.

123 Table 5 lists the braking performance standards for the various types of trains and shows the maximum distance to stop from 70 mph (113 km/h), as specified for each (this speed has been selected to facilitate comparison with the actual braking performance of HST set LA72 at Didcot on 22 August 2007).

124 For comparison, Table 5 also includes the maximum stopping distance from 70 mph for trains required to be designed in accordance with the Council Directive 96/48/EC of 23 July 1996 on the interoperability of the trans-European high-speed rail system (as defined in the rolling stock Technical Specifications for Interoperability).

Standard	Application	Maximum permitted stopping distance (in metres) from 70 mph[8]		Recommended minimum stopping distance (in metres) from 70 mph
		General	Trains operating over routes signalled for trains with 'enhanced braking' (e.g. HSTs)	
GM/RT2041 Braking system requirements and performance for trailer rolling stock and **GM/RT2042** Braking system requirements and performance for traction units	All passenger and non-passenger carrying coaching stock that does not have its own source of traction, including vehicles with a driving position but excluding those trailer vehicles that form part of multiple units. and A vehicle with its own source of traction, that is designed to haul other railway vehicles, that has one or more driving positions and is able to control the braking of the vehicles coupled to it.	1107 Ref. curve A1 on figure 1 of both standards	594 Ref. curve A3 on figure 3 of both standards	456 Ref. curve D1 on figure 1 and curve B3 on figure 3 of both standards
GM/RT2044 Braking system requirements and performance for multiple units	A fixed formation of five vehicles or less having a driving position at both outer ends of the formation. NOTE Fixed formations of more than five vehicles may meet the requirements of GM/RT2041 or GM/RT2044	1107 Ref. curve A1 on figure 1 of the standard	570 Ref. curve A3 on figure 3 of the standard	351 Ref. curve D1 on figure 1 and curve B3 on figure 3 of the standard
TSI – Rolling Stock **(2002/735/EC L245/402-506**)	Trains required to be designed in accordance with the: Council Directive 96/48/EC of 23 July 1996 on the interoperability of the trans-European high-speed rail system	-	512 Ref. table 6 in the TSI	-
GM/RT2043 Braking system requirements and performance for freight trains	Freight vehicles and on-track machines when in train formation. Applies to vehicles with an operating speed ≤ 75 mph (121 km/h).	1218 Ref. curve V on figure 1 of the standard	-	476 Ref. curve B on figure 1 of the standard
Actual performance of HST set LA72 at Didcot on 22 August 2007 (distance available to fouling point = 476 m)		-	512 (from 67.4 mph)	-
Predicted performance of HST set LA72 from 70 mph		-	548	-

Table 5: Requirements of current railway standards relating to braking performance from 70 mph (113 km/h) compared with the performance of HST set LA72 at Didcot on 22 August 2007

[8] All distances are inclusive of the distance travelled before brake force is applied to the wheels (freewheel time).

Braking performance of the HST

125 The emergency braking mode was initiated on HST set LA72 as a consequence of intervention by the TPWS at a speed of 67.4 mph (108 km/h). The following braking performance has been derived from an analysis of OTDR data:

Time for brakes to apply sufficiently for a measurable retardation of speed (*freewheel time*)	3.5 seconds
Average deceleration (excluding freewheel time)	11.35 %g
Average deceleration (including freewheel time)	9.05 %g
Distance to stop from 67.4 mph (108 km/h)	512 m

126 The above performance is compliant with the 9 %g braking specified for the original design of HSTs and the current standards for *trailer coaching stock* and *traction unit*s (RGS GM/RT2041 and GM/RT2042).

127 The performance observed during the SPAD was confirmed by practical braking tests carried out on the set involved. These tests involved operating the set at high speed and applying the emergency brake in order to measure the time and distance taken to bring the set to a stand.

128 Table 5 shows the distance to stop measured at Didcot North junction for HST set LA72 on 22 August 2007. Also shown is the predicted performance of HST set LA72 had it been travelling at the permitted maximum line speed of 70 mph at the time TPWS intervened.

Railway infrastructure and systems

The layout of track and signalling

129 Listed below are some key features of the layout of track and signalling at Didcot North junction:

- Signal SB2209 becomes visible to the driver at a distance of about 400 m. This equates to 13 seconds at 70 mph (113 km/h).
- The track layout at Didcot North junction creates a potential for a head-on collision between northbound trains and those southbound trains that are being routed across the junction towards the Up Oxford line (Figure 5). There is also the potential for a collision to occur between passenger and freight trains. Conflicting freight train movements include loaded coal trains bound for Didcot power station and elsewhere.
- The *overlap* of signal SB2209 is 185 m in length (although compliant with the standards that applied at the time of installation, recent schemes have tended to adopt a longer dimension of 225 m). The fouling point is located only 16 m beyond the end of the overlap giving a total safe overrun distance of 201 m.

Signal sighting

130 The visibility of signal SB2209 had been assessed by a Signal Sighting Committee following the incident in March 2004. The committee concluded that the aspect of SB2209 would become visible to a driver at a distance of 400 m. This was greater than the 250 m that had been assessed as the *minimum reading distance* for the signal. The committee did not identify any factors that would cause the sighting of the signal to be non-compliant with the relevant RGS, GE/RT8037, nor did it identify any additional measures other than the clearance of vegetation on the approach to signal SB2209. This finding was reflected in a recommendation of the investigation panel (paragraph 79).

131 The committee assessed that the aspect of SB913 would become visible to a driver at a distance of 1160 m. This was much greater than the 319 m that had been assessed as the minimum reading distance for the signal.

132 The RAIB investigation has identified no factors to suggest that the visibility of either signal was outside the requirements of current standards.

133 The driver of train 1W47 has not alleged any difficulty in identifying the aspect of either signal SB2209 or SB913.

Train Protection Warning System

History

134 Background information on the history of TPWS is at Appendix E.

TPWS, principle of operation

135 TPWS has been installed throughout the national network. Its current coverage includes each of the following:

- most junction signals;
- other signals where justified by the risk of a SPAD;
- in association with some permanent speed restrictions; and
- on the approach to buffer stops at terminal stations.

136 A typical arrangement of TPWS track side equipment associated with a junction signal is:

- Two closely spaced transmission loops, located between the rails at, or close to, the signal. If that signal is at danger, these loops will detect the movement of a train passing the signal causing an application of the emergency brake until the train is brought to a stand. This assembly of equipment is known as the train stop sensor.
- A pair of transmission loops, located between rails on the approach to the signal. The first of these, the arming loop, is designed to start a timer in the train mounted TPWS equipment if the associated signal is at danger. The second, the trigger loop, transmits a signal to the train mounted equipment which will cause the application of the emergency brake if the timer started by the arming loop has not elapsed. The combination of these two loops is therefore able to detect that a train is approaching the red signal at above a defined speed (the trigger speed) and cause it to be brought to a stand. This pair of loops is known as the over-speed sensor.

137 The TPWS is designed to operate without the need for the driver to be aware of the position of loops. For this reason the positions of the transmission loops described above are not identified to drivers (loops are neutral in colour and inconspicuous).

138 The principles of TPWS operation at a location similar to Didcot North junction are illustrated in Figure 8. This covers three scenarios. The first scenario is a train braking 'normally' to come to a stand 25 m on the approach to the signal. This curve is significant in that it defines the design assumption on how trains will normally approach a signal and is used in order to ensure that the over speed sensor trigger speed is set above the normal range of approach speeds.

139 The second scenario is a train approaching a red signal at the maximum permitted linespeed, and passing the over speed sensor at greater than the set trigger speed so causing the TPWS to intervene by activating the emergency braking mode.

140 The third scenario is a train passing the over speed sensor at a speed just below the set trigger speed and then maintaining that speed until passing the train stop sensor so causing the TPWS to intervene by activating the emergency braking mode.

141 In both the second and third scenarios the braking curve has been calculated for two cases. These are as follows:

- braking performance in accordance with the TPWS design assumption (2 seconds freewheel time, then a constant deceleration of 12 %g); and
- braking performance in accordance with the minimum standard required for trains operating on high speed lines (Ref. curve A3 of RGS GM/RT2041 and GM/RT2042).

The curves derived using the above assumptions are plotted on the graph at Figure 8.

142 The graph at Figure 8 demonstrates that the typical configuration of TPWS equipment is sufficient to bring a train that has passed a signal at danger to a stand before the fouling point, provided its braking performance is at least consistent with the TPWS design assumption. However, this performance cannot be assured for trains that are designed to comply with the minimum requirements of current Railway Group Standards.

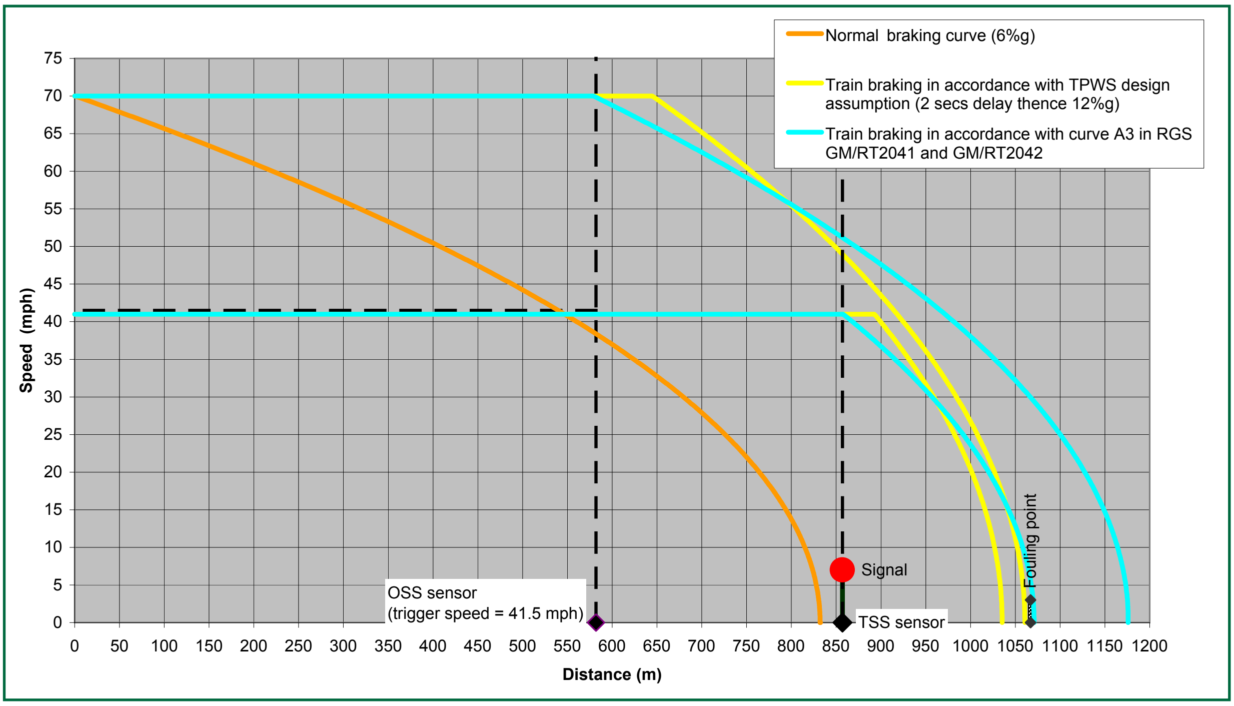

Figure 8: Typical TPWS arrangement for permitted speed of 70 mph with a 'safe over-run distance' of 201 m

Limitations

143 TPWS was never intended to mitigate all of the risk associated with signals passed at danger. Instead, it was decided to facilitate rapid and cost effective implementation by adopting a simple set of specifications for design and installation (known as the 'classic' design) that would mitigate around 75 % of the total risk. This 'classic' design solution was intended to enable the timely delivery of TPWS on the national network while adhering to the following two 'golden rules':

- the implementation of TPWS should not interfere with the normal operation of trains; and
- the implementation of TPWS should not alter or affect line capacity.

144 The design solution that emerged could not be assured of stopping a train before it reached the fouling point if either of the following conditions applied:

a. the train was travelling at a speed close to line speed and had braking performance below that assumed in the design of TPWS;

b. the train accelerated after it had passed the over speed sensor at just below the trigger speed.

145 The first of the above limitations is concerned with the braking performance of trains. This has arisen because the designers were required to adopt an assumed braking performance when deciding on the spacing of track side sensors and the settings of the timers on board trains. This 'assumed braking performance' was derived from the measured performance of modern multiple unit trains. The key values for this assumed braking performance were as follows:

● time for brakes to apply sufficiently for a measurable retardation of speed (freewheel time)	2 seconds
● average deceleration (excluding freewheel time)	12 %g
● average deceleration (including freewheel time)	10.4 %g

146 The adoption of a lower brake performance as the design assumption was given detailed consideration during the development of TPWS. However, it was concluded this would have necessitated the placing of the over-speed sensor at a greater distance from the signal, in order to allow more distance for the train to stop after TPWS intervention. This alternative would have placed the over-speed sensor at a location where it was more likely to trigger TPWS intervention on trains that were braking normally for the signal. Any attempt to mitigate the risk of unwarranted TPWS intervention by increasing the trigger speed of the relocated over-speed sensor would have had the effect of increasing the speed that trains would be permitted to approach the signal, thereby worsening the potential impact of that signal being passed at danger.

147 Currently, there is a wide range of train types operating on the network with braking performance below that used to calculate the optimum locations of the over-speed sensors and train stop sensors. These include:

- most traction units and trailer coaching stock (e.g. HST sets);
- multiple units with tread brakes (e.g. class 150 diesel multiple unit);
- freight trains; and
- some modern passenger trains designed to comply with RGS GM/RT2041, RGS GM/RT2042 (e.g. class 390, Pendolino).

Approvals

148 The design and installation rules for TPWS were approved by Her Majesty's Railway Inspectorate (HMRI) in accordance with the Railways and Other Transport Systems (Approval of Works, Plant and Equipment) Regulations 1994. This approval was given in full knowledge of the limitations of the system.

TPWS at signal SB2209

149 The track side TPWS equipment associated with signal SB2209 was installed in 2002. The locations of train stop sensors and over-speed sensors were correctly calculated in accordance with Network Rail Company Standard NR/SP/SIG/10138 – 'Train Protection and Warning System (TPWS), transmitter loop requirements and positioning'.

150 On 22 August 2007 the track side TPWS equipment was available and functioning normally. Reference to data obtained from the OTDR confirms the correct intervention by the system as train 1W47 passed over the over-speed sensor at a speed of 67.4 mph (108 km/h).

151 Inspection and testing of the TPWS equipment associated with signal SB2209 was carried out by Network Rail, at the request of the RAIB, following the incident. The testing involved measurement of the transmission loop outputs (voltage and frequency) and checks on associated signalling equipment and circuitry. The results of the tests indicated that the TPWS was operating correctly. This is confirmed by the OTDR data obtained from train 1W47.

152 The train mounted TPWS/AWS equipment was tested by First Great Western and found to be working normally.

Options for the enhancement of train protection

153 Network Rail has identified a range of options for enhancing the protection afforded by TPWS. The potential measures are recorded in a Network Rail Guidance Note issued in December 2003, RT/E/G/00028 'General guidelines on train protection and the provision of signalling', to inform designers and operators of the TPWS, and general signalling options, that may be considered when installing TPWS equipment. The main options identified in this document, that are applicable to a high risk location such as Didcot North junction, are listed below:

- 'TPWS+': this solution is proposed for those locations where the circumstances are such that an earlier intervention is necessary to ensure that a fast moving train approaching a red signal will be brought to a stand before it reaches the fouling point. It consists of an additional over-speed sensor (known as the over-speed sensor+) set at a specified distance before the standard over-speed sensor (typically located 750 m from the signal with a trigger speed set at 65 mph (105 km/h)).
- TPWS Outer Signal: this solution requires that the signal before the junction signal (the 'outer' signal) be provided with additional controls. These controls are to be such that the outer signal will only show a proceed aspect if a route has been set from the junction signal or if the train approaching the outer signal has reduced speed to the extent that it can be considered as being under control (i.e. the junction is protected by two red signals until such time as the train can be proved to have controlled its approach speed).
- Extending the overlap beyond the junction signal. This can be achieved by moving the signal (subject to sighting and signal spacing constraints) or realigning the junction. A further option is to extend the overlap across all, or part of the junction. This latter option is often technically feasible but restricts the capacity of the junction and operational flexibility.

154 Network Rail require that the need for additional TPWS and/or signalling arrangements (such as are described in RT/E/G/00028) be considered as part of any new works, or significant infrastructure alterations, if the standard TPWS provision does not ensure absolute protection or where a resulting collision could be head on.

155 For existing installations of TPWS upgrades will generally only be initiated if one, or more, of the following circumstances apply:

- infrastructure upgrade or alterations;
- following an incident, or series of incidents, or reports from train operators of problems associated with the signal;
- in response to recommendations made following a risk assessment.

Risk assessment of signalling arrangements

156 Network Rail has developed a computer based numeric tool to calculate indicative levels of risk associated with the overrunning of signals, the SAT. The SAT is designed to take into account factors such as the maximum permissible (or achievable) line speed and levels of railway traffic in order to calculate the probability that trains will pass a given signal at danger.

157 The SAT is also designed to score the average consequence of a train passing a given signal at danger. This calculation of consequence takes into account a range of variables. These include:

- the maximum permissible (or achievable) line speeds;
- the length of the Safe Overrun Distance (i.e. the distance from the signal to the fouling point);
- the level of TPWS provision associated with the signal (train stop sensors only, train stop sensors and over-speed sensor, additional sensor loops);
- the number and type of potentially conflicting train movements beyond the fouling point; and
- the type of rolling stock and its crashworthiness.

158 In addition to the above, the SAT takes into account the braking performance of trains approaching the signal. Levels of braking performance can be input based on one of three defined constant deceleration rates; 12 %g, 9 %g or 7 %g. However, the stopping distances calculated for each of these deceleration rates make no allowance for the time taken for brakes to apply sufficiently for a measurable retardation of speed (i.e. freewheel time). For this reason the distance to stop calculated by SAT for a speed of 70 mph and 12 %g deceleration is 63 m shorter than the stopping distance assumed in the design of TPWS.

159 The output of the SAT is a risk score. This score permits the comparison of different locations and the testing of potential mitigation measures and can be converted into an indicative quantified risk figure expressed in *equivalent fatalities* per annum using a conversion rate published in Network Rail's Operations Manual.

160 In March 2004 a train passed signal SB2209 at danger (paragraphs 71 to 80). Subsequently, the SAT was used as an aid to the assessment of risk at this location. The SAT calculation took into account the braking performance of HSTs by adopting an assumed braking rate of 9%g, at constant deceleration (this value of 9 %g was very similar to the average deceleration achieved by the HST during the incident on 22 August 2007).

161 The SAT assessment demonstrated that the junction exhibited a number of high risk features associated with signal SB2209 that were only partially mitigated by the provision of the 'classic' TPWS configuration. The scores obtained were:

● Risk without TPWS	**1626** (one of the highest scores in the Western Territory)
● Risk with existing ('classic') TPWS configuration (i.e. train stop sensors and over-speed sensors)	**325** (well above the average for signals fitted with TPWS)

162 The score of 325 for the existing configuration of TPWS arose because TPWS was assessed to be only 80 % effective; i.e. 1626 x (1 – 0.8) = 325.

163 On the basis of the scores given above, the team that investigated the 2004 incident recommended the installation of a supplementary over-speed sensor to intervene in case of a train approaching the signal at a speed close to the maximum permitted.

164 The findings of the SAT assessment were reviewed when tabled at a further workshop, the Detailed Assessment Workshop, on 13 October 2004. At this workshop a panel of operations, signalling and risk experts from Network Rail, First Great Western and Freightliner Heavy Haul modified some key input values (related to traffic/train type) and reached the conclusion that the actual effectiveness of the existing TPWS configuration was likely to be closer to 60 % giving a revised risk score of 650.

165 The high risk scores obtained in the SAT assessment and the subsequent Detailed Assessment Workshop were generated as a consequence of the following factors:

- high traffic levels (including a mixture of freight and passenger trains);
- head-on potential at Didcot North junction with high closing speeds; and
- a high proportion of trains with braking performance below that assumed in the design of TPWS (HSTs and all freight trains).

166 The SAT assessment for signal SB2209 was updated following the incident on 22 August 2007. This update incorporated:

- updated traffic/train type data derived from the Summer 2007 Working Timetable;
- the effectiveness of TPWS was calculated in line with new guidance contained in the current Operations Manual; and
- some minor corrections to the original input data (e.g. an extended distance to the fouling point).

167 The above update assessed the effectiveness of the existing TPWS configuration as 50 %, giving an overall risk score of 835.

168 The current Operations Manual gives guidance on using the SAT risk score, converted to a measure of equivalent fatalities, to calculate the safety benefit for comparison with the cost of enhancing signalling schemes. Application of this guidance to the circumstances that applied at Didcot North junction between 2004 and 2007 shows that the levels of risk that had been identified were sufficient to justify a value of investment at least equal to the typical cost of an additional OSS (see Table 6).

Assessment	Score	Equivalent fatalities (per annum)	Value of investment justified by risk (£)[9]
			Assuming the value of preventing a fatality to be £1.5 million (as per guidance in the current Operations Manual)
Detailed Assessment Workshop, October 2004	650 (TPWS 60% effective)	6.66E-03	35862
SAT, September 2007	835 (TPWS 50% effective)	8.82E-03	59155
Typical cost of one additional OSS loop			25000

Table 6: Value of investment justified by risk at signal SB2209 (calculated according to the Network Rail Operations Manual)

The regulation of trains

169 Immediately before the incident both train 1W47 and 2P66 were running behind schedule. As a consequence both trains approached the junction at the same time and the Automatic Route Setting system elected to route train 2P66 across the junction ahead of train 1W47, thereby maintaining the order that the two trains were scheduled to cross the junction. This action was commanded by the system following the execution of an embedded algorithm and without the intervention of the signaller at Swindon Signalling Control Centre.

170 The Automatic Route Setting system involved in this incident was commissioned in 1995 as part of the Integrated Electronic Control Centre at Swindon Signalling Control Centre and has not been significantly modified since. Its commands on 22 August 2007 were correct to the extent that no signalling principle, or operating rule, was breached. The decision to route train 2P66 across the junction ahead of train 1W47 arose because Automatic Route Setting system computed that the minimisation of overall delays was best served by routing the two trains across the junction in the scheduled order, thereby incurring minor additional delays to train 1W47. A similar decision might well have been taken by a signaller.

[9] Using guidance contained in the Network Rail Operations Manual (procedure 5-14). Assumes an annual maintenance cost of £5000, an asset lifetime of 10 years, and an annual discount rate of 6.5%. It also assumed that any enhancement of TPWS would achieve 95% effectiveness.

Analysis

Identification of the immediate cause

171 Signal SB2209 was passed at danger because the driver did not respond correctly to the aspect of the previous (caution) signal, SB913.

Factors influencing the driving of the train

172 The RAIB has carried out an analysis of the actions taken by the driver in order to identify those factors that may have influenced his behaviour on the approach to signal SB913. The analysis was performed by assessing a range of possible factors against the available evidence in order to derive a measure of the relevance of each. It identified a number of factors as having the most relevance to the incident. These are as follows:

1. An expectation that the aspect of signal SB913 would change from yellow to a less restrictive aspect causing the driver not to register that signal SB913 was still showing a yellow aspect.
2. An inappropriate driving technique on the approach to signal SB913 causing the train to approach at an excessive speed.
3. A lack of focus on the driving task.

173 Each of these is now considered in turn.

<u>Expectation</u>

174 The first of the above factors is expectation. The presence of this factor would explain why the driver applied power after seeing a yellow aspect on signal SB913 and then took no steps to reduce the speed of his train. An expectation that signal SB913 would clear to a less restrictive aspect could have been the result of:

- a conscious evaluation of the situation; or
- the unconscious processing of information.

175 The former possibility is thought to be unlikely given the experience and knowledge of the driver whereas his experience and knowledge would not preclude the latter.

176 Expectation errors often occur because drivers develop mental models of the situation they are faced with and such models are then difficult to override. In this case the driver's mental model appears to have included an expectation that the signal would clear. This mental model is likely to have arisen for the following reasons:

- express trains routed via the Down Avoiding line are only rarely stopped at Didcot North junction and the driver had no recollection of being stopped at signal SB2209.
- the driver recalled that on a number of previous occasions the aspect of signal SB913 changed from red, to yellow, to double yellow, and then green, in quick succession as his train approached.

177 A further possibility is that the driver had formed a subconscious expectation that the aspect of signal SB913 would step up to a less restrictive aspect as his train approached, as had often been his experience at the previous signal SB905. The expectation that signal SB913 would clear to a less restrictive aspect caused the driver to neither register the aspect of signal SB913 nor prepare his train to stop at signal SB2209.

Driving technique

178 The analysis described at paragraphs 174 to 177 indicates that the driver maintained the speed of his train while driving towards a yellow aspect in the expectation that it would step up to a less restrictive aspect.

179 Had the driver approached signal SB913 at a lower speed he would have increased the time available to recover from any error and mitigated the severity of the outcome should he not respond to the signal. Furthermore, by placing the power controller in the OFF position and the brake at step 1 he would have put in place an effective reminder that he was approaching a caution signal.

180 The driver had been the subject of the lowest level of enhanced monitoring because of concern expressed about his driving technique following the TPWS intervention at Moreton-on-Marsh in 2006. Nevertheless, there is no evidence that the driver routinely drove in a reckless or incautious manner. All reports following cab rides by managers were favourable about his style of driving and OTDR reviews exposed no evidence of inappropriate driving. The heavy braking earlier in his journey with train 1W47, at Slough, appears to have been due to a lack of focus on the driving task rather than an example of aggressive driving. This is evidenced by the fact that the driver had cut power earlier than he needed to on the approach to Slough.

Loss of focus on the driving task

181 Neither an expectation that signal SB913 would clear to a less restrictive aspect, nor his inappropriate driving style, would have led to signal SB2209 being passed at danger had the driver remained focused on all aspects of the driving task.

182 There is evidence that the driver had previously lost concentration as his train approached Slough (paragraph 52), resulting in a heavy brake application. Similarly, there is evidence that the driver lost focus on the driving task as his train approached signal SB913. As a consequence the driver did not become aware that signal SB913 was still showing a yellow aspect (despite an AWS warning).

Distraction

183 The investigation has considered whether the driver had become distracted by his driving task or by events beyond the railway boundary. The former is possible but unlikely given the relatively routine nature of the driving task. In the case of external events, it is known that the driver saw a plume of smoke on his approach to signal SB913. This was of interest to him because the smoke was emerging from the Didcot Railway Centre (Great Western Society steam centre) and he had a general interest in steam locomotives. He also recalled seeing a person dressed in historical dress standing on the Great Western Society platform that is adjacent to the Down Avoiding line.

184 These external events may have caused the driver to become distracted. However, neither event would have been likely to have become a serious distraction to the driver until his train had already passed signal SB913. For this reason neither is considered to have caused train 1W47 to pass signal SB2209 at danger. However, it is possible that train 1W47 would have braked one or two seconds earlier had the driver been paying close attention to the aspect of signal SB2209. For this reason it is concluded that the external distractions are likely to have caused the driver not to react to the aspect of signal SB2209 before the TPWS intervened.

Situational awareness

185 A model that is appropriate to the analysis of the factors that applied to the incident at Didcot is known as 'situational awareness'. Situational awareness is defined as follows:

> 'the perception of elements in the environment within a defined volume of time and space, the comprehension of their meaning, and the projection of their status in the near future'[10]

186 In January 2006 the RSSB published a report into the subject of route knowledge. This study was carried out by a team of human factors specialists employed by Air Affairs (UK) Ltd. This study highlighted the importance of situational awareness as a key requirement for train driving. The study identified that situational awareness comprises a static element; i.e. the driver's knowledge of route features and risk; and a dynamic element. The dynamic element is associated with the application of knowledge and skills in order to correctly comprehend a situation and implement appropriate actions.

187 In the case of the incident at Didcot the driver had a more than adequate 'static' knowledge of the route. Nevertheless, his comprehension of the situation was deficient. It is possible that this deficiency would not have arisen had he been exposed to that route on a more frequent basis (paragraph 99) and therefore given more opportunity to encounter different sequences of signal aspects. For this reason the level of situational awareness and the driver's infrequent exposure to the route via the Down Avoiding line are considered to be factors for consideration.

Other factors

AWS

188 The driver of train 1W47 heard two AWS warnings, six seconds apart, as his train approached signal SB913 (the first related to a temporary speed restriction in the station and the second to the restrictive aspect on the signal).

189 The RAIB has sought to determine whether the proximity of the two warnings was an influencing factor relative to the incident that followed. Two scenarios were considered:

- the presence of the first warning was a distraction; or
- the presence of two warnings caused the driver to become confused.

190 Although both of the above scenarios are feasible, neither is supported by any evidence.

191 The most likely explanation for the driver failing to register the aspect of signal SB913 despite cancelling the warning at the AWS magnet is a combination of the following:

- a lack of focus on the driving task (paragraph 182);
- the driver cancelled the AWS warnings by force of habit; and
- the warning associated with the yellow aspect was the same that would have applied had the signal been showing a double yellow aspect (i.e. the AWS warning was not inconsistent with the driver's expectation that the aspect would become less restrictive).

Flashing aspects

192 The RAIB has considered whether the flashing yellow aspect sequence on the approach to Moreton Cutting junction could have contributed to the driver's expectation that the route was set for his train onto the Down Avoiding line and through Didcot North junction.

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[10] RSSB report (T150) 'Route Knowledge Study' 23 January 2006

193 A similar scenario occurred at Colwich junction in 1986, shortly after the introduction of flashing aspects on the approach to certain junctions.

194 There is no evidence to suggest that this was a factor in the incident at Didcot on 22 August 2007. It also observed that the similar SPAD that occurred in March 2004 involved a train that had approached via the Down Relief line and had not therefore encountered flashing aspects.

The effect of ATP mode change at Moreton Cutting junction

195 There is no evidence that the removal of the ATP visual display, and the disablement of full ATP protection, as the train was routed across Moreton Cutting junction was a factor in the incident at Didcot on 22 August 2007.

Driving policy

196 The ATOC guidance note gave limited advice to train operators on an appropriate driving style when approaching signals with restrictive aspects. 'Shutting off power' is identified as an option for consideration by drivers when approaching a signal with a restrictive aspect. However, no guidance is given to train operators on the circumstances when this should be done.

197 The First Great Western driving policy booklet advises drivers that it is good practice to apply the brake before reaching the AWS magnet of the first cautionary signal when travelling at or near line speed. This implies that the driver of train 1W47 should have cut power and started to brake before passing signal SB905 and continued to brake on his approach to SB913 until such time that the signal cleared to a less restrictive aspect.

198 Although the intent of the First Great Western policy appears sound, the above guidance is presented as being 'good practice' rather than a requirement of safe driving. In addition there is scope for misunderstanding the guidance on braking when approaching the 'first cautionary signal' because it is not clear whether the text relates to the first signal displaying a yellow aspect or the first signal displaying a double yellow aspect.

199 At the time of the incident First Great Western had no formal process for drivers to be assessed for compliance with the above guidance. However, the management team have expressed an expectation that the drivers' managers would correct any instance they observed of a driver failing to regulate speed after passing the preliminary caution signal.

200 The RAIB considers that First Great Western provide insufficient guidance on how drivers should respond to caution and preliminary caution signals. Had the guidance been clearer, and steps been taken to monitor and encourage compliance, it is possible that the driver involved in the SPAD on 22 August 2007 would have waited until he had observed the aspect of signal SB913 change to a less restrictive aspect before applying power.

First Great Western's management of driver competence and SPAD risk

201 First Great Western had in place a process for the management of driver competence designed to be compliant with the requirements of RGS GO/RT 3251 (Train Driving). First Great Western records indicate that the mandated process had been correctly applied in the previous two years in relation to the driver involved in the incident.

202 First Great Western's strategy for the management of SPAD risk included:

- the selection of individuals with the correct personal qualities (by means of techniques such as structured interviews and psychometric testing);
- initial training and assessments of suitability against predetermined criteria;
- a competence management system (including traction and route knowledge);
- the promotion of good practice in driving by means of Professional Driving standards and briefing;
- monitoring by qualified managers;
- investigation of incidents; and
- participation in Network Rail reviews of signal sighting.

203 Despite the above, First Great Western's 'SPAD rate per 100 drivers employed' grew between 2005 and 2007. In 2007 this measure of SPAD performance was 54 % above the national average for train operating companies.

204 The 'SPAD rate per million train miles operated' saw a nearly three-fold increase between 2005 and 2007. Using this measure First Great Western's SPAD performance rose from a level well below the national average to a level slightly above the national average over three years.

205 This increase in the First Great Western 'SPAD rate' is partially explained by the high rates recorded for the former Wessex Trains and Thames Trains franchises. However, these values are higher than might have been expected given the fact that, unlike most other train operating companies[11], about 40 % of the First Great Western fleet, and around 15 % of its route mileage, are fitted with Automatic Train Protection equipment which will tend to reduce the likelihood of a signal being passed at danger without authority.

206 First Great Western was aware of the deterioration in its performance between 2004 and 2007 and has carried out an analysis with the objective of understanding the reasons and implementing corrective measures (paragraph 248).

207 In the case of the section of route between Didcot and Oxford, First Great Western have assessed that drivers require to be exposed to the route (by driving or refresher trips) three times in 26 weeks. At present there is no means to judge the adequacy of this frequency. Neither Railway Group Standards nor ATOC guidance provide any indication as to the minimum frequency required to retain route knowledge. The RAIB has found no RSSB or other industry research that provides any measure of the exposure required in order for drivers to retain sufficient route knowledge.

208 It is also observed that First Great Western had no mechanisms in place to systematically monitor and review how often drivers are actually exposed to each of the routes they have signed for. This is contrary to the requirement in RGS GO/RT 3251 that train operators have 'systems to prevent a driver who has not operated over a route in a specified period from driving that route without appropriate training'.

209 The monitoring of drivers' exposure to routes is likely to be of greater importance at a depot such as Bristol where drivers are required to work over many routes.

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[11] The only train companies on the national network with ATP fitted rolling stock are Chiltern Railways, Eurostar, First Great Western and Heathrow Express.

Train braking performance

210 The braking performance of set LA72 has been assessed using OTDR data and subsequent testing. This has shown that the set braked in accordance with its specification and the minimum requirements of current standards. For this reason the performance of the braking system of set LA72 is not considered to be causal or contributory.

Adequacy of the signalling/TPWS arrangements

National context

211 Trains are still operating with braking performance below that adopted for TPWS. Such trains currently include passenger trains with tread brakes (e.g. the class 15x diesel multiple units and most coaching stock) and many types of locomotive and freight rolling stock.

212 Even new passenger trains designed in accordance with the current Railway Group Standards are not guaranteed to possess braking performance consistent with that specified for TPWS. The graph at Figure 9 shows that the minimum braking performance specified for new trailer coaching stock and multiple units in RGS GM/RT 2041 and 2044 is below that assumed in the design of TPWS.

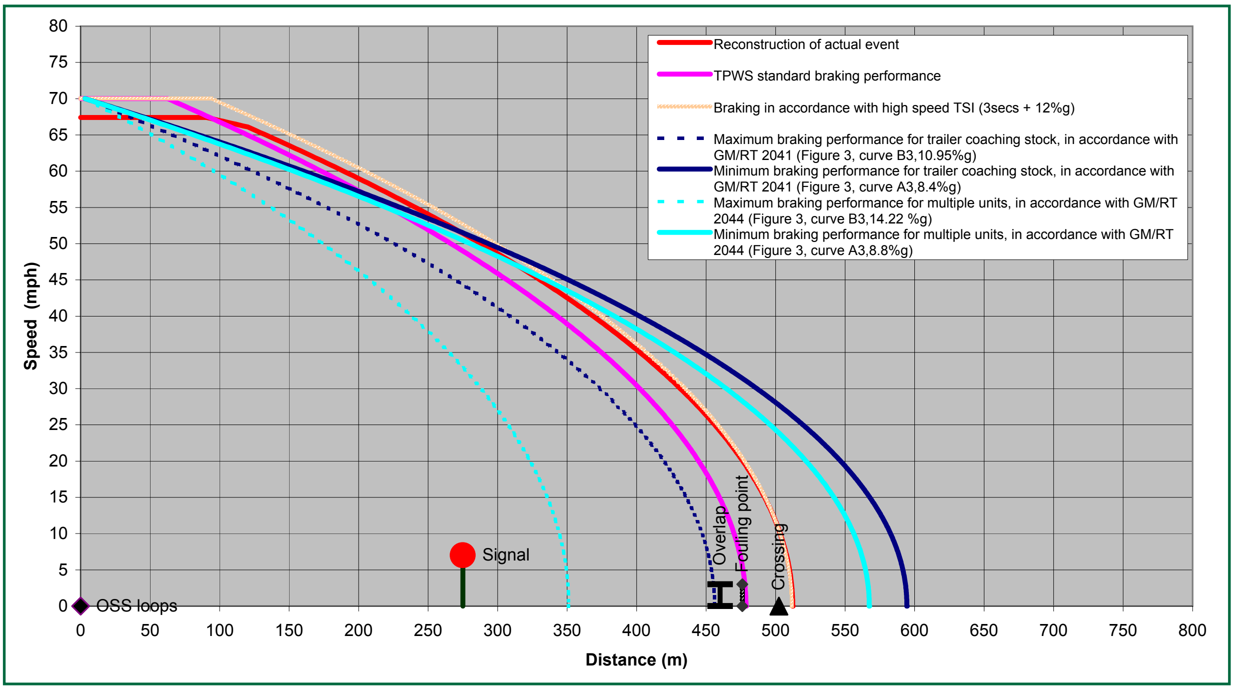

Figure 9: Standard braking curves from 70 mph following TPWS intervention at OSS loops ('classic' TPWS configuration - as signal SB2209, Didcot)

213 If further improvements are to be made in the risk performance at high risk junctions there is a range of potential measures that can be considered[12] (see also paragraph 153). These fall into four main categories:

a. enhancement of the signalling provisions (e.g. extended overlaps, greater signal spacing);

b. additional TPWS provisions (e.g. additional loops);

c. improved braking performance of rolling stock using the route; and

d. operational controls (e.g. reduction of approach speeds or introduction of special regulating requirements).

214 In all cases there is a need for systematic risk assessment using a validated technique. In those cases where there is shown to be a significant risk, additional measures should be implemented unless it can be shown to be not reasonably practicable to do so.

215 When assessing reasonable practicability there is a need to take into account the potential operational disbenefits that can be introduced if the TPWS provisions are only optimised for one train type on a line with mixed traffic. These disbenefits can include a loss of overall line capacity and a greater likelihood of unnecessary tripping of trains.

<u>Local context</u>

216 The TPWS equipment associated with signal SB2209 intervened correctly, and had been installed in accordance with the design and relevant standards. Had the design of the TPWS configuration allowed for the braking characteristics of an HST the SPAD would still have occurred (TPWS is not designed to prevent SPADs but is instead designed to stop trains before they reach the fouling point). However, an enhanced configuration would have prevented train 1W47 from fouling Didcot North junction (i.e. reduced the severity of the outcome). The TPWS, as installed at this location, was therefore a causal factor associated with the subsequent near-miss.

217 Signal SB2209 was passed at danger in March 2004. Following this event a preliminary risk assessment was carried out using Network Rail's SAT. This was then reviewed in a subsequent workshop. These assessments showed that the existing configuration of TPWS had only limited effectiveness at this location and that the risk associated with signal SB2209 was among the highest for any signal in the Western Territory.

218 The above risk assessments were complete by October 2004. Despite the results obtained the management process that was in place did not translate the findings of the risk assessment into reasonably practicable measures to address the risk identified. Consequently, no actions were taken to submit a business case for implementation until the middle of 2006.

219 The absence of management action in response to the findings of the risk assessment is seen as an underlying management factor.

[12] See also appendix B of RGS GM/RT 2041 for potential mitigation measures.

220 In September 2004, the local Recommendations Review Panel accepted the recommendation that an additional over-speed sensor be provided on the approach to the signal but assessed the risk as 'low' and therefore set a three year target for implementation. In April 2007 the Recommendations Review Panel agreed to an extension to the target date for implementation to 2009 in response to a concern raised by the Territory Signal Engineer that there was limited resource to undertaken the design and installation work. In both cases it appears that the Recommendations Review Panel made their decision despite the high risk ranking of signal SB2209 and without reference to the risk assessment or cost/benefit analysis.

221 Had the Recommendations Review Panel fully recognised the risk implications of the signalling arrangements at Didcot it is likely that the decision would have been taken to install the additional over-speed sensor that had been recommended. This action would have provided a means of stopping train 1W47 before it fouled Didcot North junction. For this reason the non-recognition of the risk implications of the signalling arrangements at Didcot by the Recommendations Review Panel is considered to be an underlying management factor.

The regulation of trains

222 The commands of the Automatic Route Setting on 22 August 2007 were logical in terms of minimising overall train delays. However, the decision to route train 2P66 across the junction ahead of train 1W47 created the potential for a head-on collision. Had train 1W47 been routed across the junction ahead of train 2P66 the position of the 9057 points would have removed any such potential.

223 The independent report prepared by Sir David Davies[13] as an input to the joint inquiry into train protection systems proposed that the railway industry look at the feasibility of adapting *traffic regulating rules* in order to ensure that trains that experience restrictive aspects are always the ones that can be protected by TPWS. This proposal implied that Automatic Route Setting should adopt the safety risk of overrun as a criterion when computing the order that trains should be signalled across a junction.

224 Professor John Uff and Lord Cullen considered Sir David Davies' proposal as part of their joint inquiry. They reported that the proposal had serious commercial implications, represented a reversal of signalling policy and was not supported by an analysis of the safety gain. Consequently, no recommendation was made that this concept be investigated further and the railway industry has not taken the proposal forward.

225 In the case of signal SB2209, it is technically feasible to alter the Automatic Route Setting algorithms to include a calculation of the potential risk following a signal being passed at danger. However, the case for doing so is doubtful since the risk can be significantly reduced by enhancing the level of TPWS provision. Furthermore, such changes may introduce unintended increases in risk at adjacent junctions.

226 A further option would be to modify the timetable to reduce the potential for head-on collisions at Didcot North junction. Although theoretically possible, the option would introduce a major timetabling constraint affecting numerous freight and passenger services.

[13] Automatic Train Protection for the Railway Network in Britain – A Study (D E N Davies) published by The Royal Academy of Engineering, February 2000.

Observations on issues arising during the investigation

Network Rail's management of SPAD risk

227 Network Rail's process and tools (described in Company Standard NR/SP/SIG/14201, 'Prevention & mitigation of overruns – risk assessment of signals') provide a means of comparing risk at different locations and assessing the risk benefit of enhancements. It can also be used to give a crude assessment of societal risk which can then be input to cost/benefit analyses.

228 The SAT only permits a limited number of constant deceleration rates to be taken into account; 7 %, 9 %, and 12 %g with no allowance for freewheel time (paragraph 158). In the case of the assessments carried out for Didcot the 9 %g deceleration was a reasonable approximation of the braking performance of HSTs. However, the 7 %g value is optimistic for a freight train given that the current standard for the braking of freight rolling stock (GM/RT 2043) specifies a minimum deceleration equivalent to 4.1 %g (freight train braking curves are to be found at Appendix C). The actual performance of freight trains can sometimes be better than that specified in the standard but will only rarely achieve a mean deceleration of 7 %g.

229 Although the SAT is a useful tool, it is in need of enhancement to better enable the calculation of TPWS effectiveness for all possible mean braking rates between 4 % and 12 %g with allowance for the time taken for brakes to take effect (freewheel time). Once this is done all existing SAT risk assessments should be reviewed.

230 The investigation has also found that the risk 'score' derived in a SAT assessment can be greatly influenced by any assumptions made by the risk assessor when inputting data. The SAT is particularly sensitive to data inputs concerning:

- traffic levels and service patterns;
- types of train; and
- braking performance.

231 For this reason it is important that SAT assessors are competent and are provided with accurate data.

Conclusions

Immediate cause

232 Signal SB2209 was passed at danger because the driver did not respond correctly to the aspect of the previous (caution) signal, SB913.

Causal factors associated with signal SB2209 being passed at danger

233 Signal SB2209 was passed at danger because of the actions of the driver of train 1W47 on the approach to signal SB913. The most likely explanation for these actions is a combination of the following:

- the driver's expectation that signal SB913 would clear from yellow to a less restrictive aspect (paragraphs 174 to 177);
- the formation in his mind of an inappropriate mental model of the situation he was encountering (paragraph 176);
- a loss of focus on the driving task leading to the driver not registering the aspect of signal SB913 on his approach (paragraphs 181 and 182); and
- the cancelling of two AWS warnings in quick succession without checking the aspect of the signal ahead (paragraph 191).

Causal factors associated with the subsequent near-miss

234 The following factors are considered to have caused train 1W47 to stop foul of Didcot North junction, narrowly avoiding a collision with train 2P66:

a. the late identification of signal SB2209 at red due to external distractions associated with the Didcot Railway Centre (Great Western Society steam centre) (paragraph 184).

b. the braking performance of the HST set involved in the incident was below that assumed for the design of the TPWS at signal SB2209 although it exceeded that needed to comply with the Railway Group Standards for braking (paragraphs 211 to 221 and Recommendations 2, 3 and 4).

Contributory factors

235 The RAIB concludes that the driver of 1W47, at no stage, believed that the single yellow aspect on signal SB913 had changed to a less restrictive aspect. Nevertheless, the driver applied power to maintain the speed of his train in the expectation that the aspect would change. This driving behaviour is considered to have been a contributory factor (paragraphs 179 and 200 and Recommendation 1).

Underlying factors

236 Network Rail had not yet installed enhanced TPWS equipment at this location following an earlier SPAD despite there being a clear case for doing so following risk assessments that had been performed, and a recommendation by the investigation panel that this be done (paragraphs 218 and 221, and Recommendation 5).

237 The local Recommendations Review Panel did not recognise the risk implications of the signalling arrangements at Didcot when considering the timescale for implementation of recommendations made following the investigation into the earlier incident (paragraph 221 and Recommendation 5).

Additional observations

238 The industry gives drivers insufficient guidance on how they should respond to caution and preliminary caution signals (paragraph 196 and Recommendation 6).

239 Although the evidence is uncertain, it is possible that poor situational awareness, arising from the driver's infrequent exposure to the route he was driving, was a factor in the circumstances that led to the SPAD (paragraph 187 and Recommendations 7 and 8).

240 First Great Western had no mechanisms in place to systematically monitor and review how often drivers are actually exposed to each of the routes they have signed for (paragraph 208 and Recommendation 7).

241 There is no guidance to train operators on the frequency at which drivers should be exposed to routes if they are to retain adequate route knowledge (paragraph 115 and Recommendation 8).

242 There is a need for enhancement of Network Rail's SAT to better enable the calculation of TPWS effectiveness for all possible mean braking rates between 4 % and 12 %g (paragraph 229 and Recommendation 9).

243 The risk 'score' derived by use of the SAT can be greatly influenced by any assumptions made by the risk assessor when inputting data. The tool is therefore reliant on correct data inputs for factors such as braking performance, traffic levels, service patterns and the types of train. (paragraphs 229 and 230, Recommendations 2 and 9).

244 First Great Western's SPAD performance deteriorated markedly between 2005 and 2007 (paragraph 205).

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

245 Network Rail has installed supplementary over-speed sensor loops on the approach to signal SB2209 at Didcot (paragraphs 213, 220 and 234b). The RAIB was minded to make a recommendation in this area, but is content that the installation work has already been completed and is now in service.

246 Network Rail has asked its Operations Safety Reliability Availability and Maintainability (OPSRAM) groups to review, with reference to the risk assessments, conditions when TPWS may not be effective. The review is to include braking below 12 %g, short overlaps and low adhesion conditions.

247 'Red Alert', an information newsletter aimed at train drivers and other operating staff, has published an article on the limitations of TPWS.

248 First Group has carried out an extensive management review of its SPAD performance. This has resulted in the implementation of a detailed action plan covering issues such as driver competence, driver management, liaison with Network Rail, data analysis and processes for responding to recommendations following SPADs.

249 Working groups were established to take forward the action plan and the strategy was presented to the First Executive Safety Committee on 22 April 2008.

250 First Great Western's SPAD performance shows signs of significant improvement during 2008.

Recommendations

251 The following safety recommendations are made[14]:

Recommendations to address causal, contributory and underlying factors

1 First Great Western should review its driving policy with the objective of enhancing its guidance on driving technique when approaching signals that are showing restrictive aspects. This review should include consideration of the principle that when travelling at or near the maximum permitted line speed drivers should not apply power after passing a signal with a restrictive aspect and should not subsequently reapply power until the aspect of the next signal is observed to be no more restrictive than the signal they have just passed (paragraph 235).

Having completed the above review First Great Western should ensure that its drivers are briefed on any changes to the driving policy and trained accordingly.

2 Network Rail should, in consultation with train operators, review its existing risk assessments for all existing junction signals in order to verify that:

- the actual braking performance of trains signalled by that route has been correctly taken into account; and
- proper consideration has been given to any reasonably practicable measures identified.

(paragraphs 234b and 236)

When addressing this recommendation Network Rail should ensure that risk assessors are competent and have access to accurate input data (paragraph 230).

3 In support of Network Rail's assessment of risk at junction signals (see Recommendation 2), RSSB should make a 'proposal', in accordance with the Railway Group Standards Code, to amend Railway Group Standards to require train operators, in consultation with rolling stock owners, to publish and disseminate to Network Rail any detailed data they may possess relating to the actual braking performance of the trains they operate on the national network (for a range of typical train formations). This should include the distance to stop from a range of speeds (or the duration of any freewheel time and the subsequent rate of deceleration) (paragraphs 242 and 243).

continued

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[14] 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 ORR/HMRI 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 167 to 171) can be found on RAIB's web site at www.RAIB.gov.uk.

4 RSSB, in consultation with industry stakeholders, should review the practicability of enhancing the minimum emergency braking performance mandated for new passenger trains in Railway Group Standards. The objective of any such enhancement shall be to improve consistency between the minimum braking performance of new passenger trains and the design of train protection systems in use on the network. If shown to be reasonably practicable, RSSB should make a 'proposal', in accordance with the Railway Group Standards Code, to amend Railway Group Standards accordingly (paragraph 212).

5 Network Rail should review its management processes with the objective of ensuring that:

- the findings of signal and layout risk assessments (using tools such as SAT) are translated into reasonably practicable measures to address the risk identified (paragraph 236); and
- relevant risk assessments are properly considered when reviewing the actions to be taken in response to recommendations made following investigations (paragraph 237).

Recommendations to address other matters observed during the investigation

6 ATOC should review its guidance note ATOC/GN007 with the objective of clarifying the advice to passenger train operators on good practice for driving technique when approaching signals displaying a restrictive aspect. This review should give detailed consideration to the adoption of the principle outlined in Recommendation 1 (paragraph 238).

7 First Great Western should review its systems for the management of route knowledge with the following objectives:

- to assess whether the extent of current route knowledge required by its drivers is compatible with the need for drivers to retain adequate situational awareness.
- to assess whether the currently mandated minimum frequency of exposure to each route is sufficient (this review should be updated when the actions at Recommendation 8 have been completed).
- to put in place systems for monitoring the actual exposure of drivers to each route they have signed for.
- to assess the adequacy of driver training and competency management systems related to route learning and the retention of route knowledge.

(paragraphs 239 and 240)

8 RSSB, in consultation with ATOC, and with reference to project T655, should carry out further research into the periodicity of driving turns/refresher training required to acquire and retain route knowledge (paragraph 241).

continued

9 Network Rail should ensure that its methodology and computer systems for assessing the risk associated with signal overruns correctly take into account the actual braking performance of all trains scheduled to pass a signal. This should allow for freewheel time and the subsequent average deceleration (paragraph 242).

Appendices

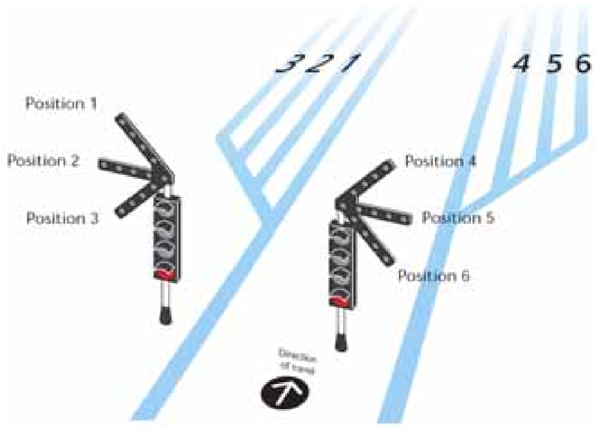
Appendix A - Glossary of abbreviations and acronyms

ATOC	Association of Train Operating Companies
AWS	Automatic Warning System
HMRI	Her Majesty's Railway Inspectorate
HST	High Speed Train
m	Metres
mph	Miles per hour
OPSRAM	Operations Safety Reliability Availability & Maintainability
OTDR	On-Train Data Recorder
RAIB	Rail Accident Investigation Branch
RSSB	Rail Safety & Standards Board
SAT	Signal Assessment Tool
SPAD	Signal Passed at Danger
TPWS	Train Protection Warning System

Appendix B - Glossary of terms

Approach released	The clearing of a signal when the approaching train has been proved to have stopped at the signal, or to have reduced speed sufficiently to observe the correct speed over a junction/route with a restricted speed.
Arming loop (TPWS)	The first in the pair of TPWS transmission loops that form a TPWS sensor (over-speed or train stop), located between rails on the approach to the signal. In the case of an over-speed sensor, the arming loop is designed to start a timer in the train mounted TPWS equipment if the associated signal is at danger.
Automatic Route Setting	A system for setting routes without the action of the signaller, based upon a stored timetable, train running information, defined priority, selection criteria and operating algorithms.
Automatic Train Protection	A safety system that enforces either compliance with or observation of speed restrictions and/or signal aspects by trains.
Automatic signal	A signal controlled by the passage of trains. It does not require any action by the Signaller or ARS.
Automatic Warning System	A track inductor based system linked to the aspects of fixed line side signals that provides audible and visual warnings to the driver on the approach to signals, certain level crossings and emergency, temporary and certain permanent speed restrictions.
Controlled signal	A signal that is cleared from red from a control centre by a signaller, or ARS, on each occasion it is required to show a proceed aspect.
Defensive (driving)	A train driving technique which actively encourages a driver to anticipate and respond appropriately to operating and environmental conditions (e.g. the early control of speed on the approach to cautionary and stop signals).
Down Avoiding line	At Didcot, this is the line that normally conveys trains from the direction of London towards Oxford, avoiding Didcot Parkway station.
Down Main Line	At Didcot, this is the line that normally conveys westbound fast trains (i.e. away from London).
Down Relief Line	At Didcot, this is the line that normally conveys westbound slow trains (i.e. away from London).
Equivalent Fatalities	The sum of fatalities and injuries weighted in proportion to their severity such that a number of injuries will be valued as the equivalent to one fatality (also known as Fatalities and Weighted Injuries; FWI).
Fatigue Index	A measure of risk associated with work-related fatigue.
Formal investigation	An investigation led by Network Rail involving representatives of the companies involved in the incident in accordance with a formal remit.

Fouling point	The place where a vehicle standing on a converging line would come into contact with a vehicle passing on the other line.
Four aspect (signal)	A colour light signal capable of displaying one of four main aspects. These are: o single green light (proceed); o two yellow lights (preliminary caution); o single yellow aspect (caution); and o red (danger/stop).
Freewheel time	The time elapsed between the command for the brakes to apply and the first measurable retardation of speed.
g	The force of acceleration (deceleration) due to gravity; equal to 9.81 m s^2.
Junction indicator	An array of white lights mounted on a colour light signal that illuminate to indicate to the driver that the train is being routed to the left or right of the straight route. Junction indicators can be located in one of six 'positions' in order to identify the route being taken (as indicated in the diagram below):



Minimum reading distance	The location on the train's approach to the signal at which the assessed 'minimum reading time' is available. The 'minimum reading time' is the sum of the times assessed to be essential in order for a driver approaching a signal to: a) detect the presence of the signal; b) identify the signal as being applicable to the driver; c) observe the information presented by the signal and d) interpret the information to determine what action, if any, is required.
National Radio Network	A dedicated radio network operated and maintained by Network Rail that allows direct communication between driver and network controller.
Overlap	The distance beyond a stop signal that must be clear, and where necessary locked, before the stop signal preceding the stop signal in question can display a proceed aspect.

Overspeed Sensor	The TPWS overspeed sensor (OSS) is located on the approach to the associated signal and is designed to trigger the application of emergency braking if the train is approaching a red signal at an excessive speed.
Railway Group Standard(s)	A document produced pursuant to the Railway Group Standards Code (the Code) defining mandatory requirements in respect of the mainline railway. RGSs must be complied with by those infrastructure managers who hold a safety authorisation issued in respect of the GB mainline railway.
Restrictive aspect	Any main signal aspect other than green.
Sighting distance	The distance from a signal to its sighting point (the 'sighting point' is the furthest point from a signal at which the driver can reliably read the aspect of a signal and / or route indication).
Three Aspect (signal)	A colour light signal capable of displaying one of three main aspects. These are: o single green light (proceed); o single yellow aspect (caution); and o red (danger/stop).
Traction Unit	A vehicle with its own source of traction, that is designed to haul other railway vehicles, that has one or more driving positions and is able to control the braking of the vehicles coupled to it.
Traffic regulating rules	Rules applied by signallers, or programmed in the Automatic Route System, when deciding on priorities between trains at junctions.
Trailer Coaching Stock	All passenger and non-passenger carrying coaching stock that does not have its own source of traction, including vehicles with a driving position but excluding those trailer vehicles that form part of multiple units.
Train lines	Electrical wires which carry control signals along the length of a train.
Train Protection Warning System	The primary purpose of the Train Protection and Warning System (TPWS) is to minimise the consequence of a train passing a TPWS fitted signal at danger and a train over-speeding at certain other locations on Network Rail controlled infrastructure. The Train Protection and Warning System (TPWS) is designed to be compliant with the train protection requirements of the Railway Safety Regulations1999.
Train Stop	The TPWS train stop (TSS) is located adjacent to the associated signal and is designed to trigger the application of emergency braking if a train passes over it when the associated signal is showing a red aspect.

Trigger loop (TPWS)	The second in the pair of TPWS transmission loops that form a TPWS sensor (over-speed or train stop), located between rails on the approach to the signal. In the case of an over-speed sensor, the trigger loop transmits a signal to the train mounted equipment which will cause the application of the emergency brake if the timer started by the arming loop has not elapsed.
Up Oxford Line	At Didcot, this is the line that normally conveys trains from Oxford towards Didcot Parkway station.

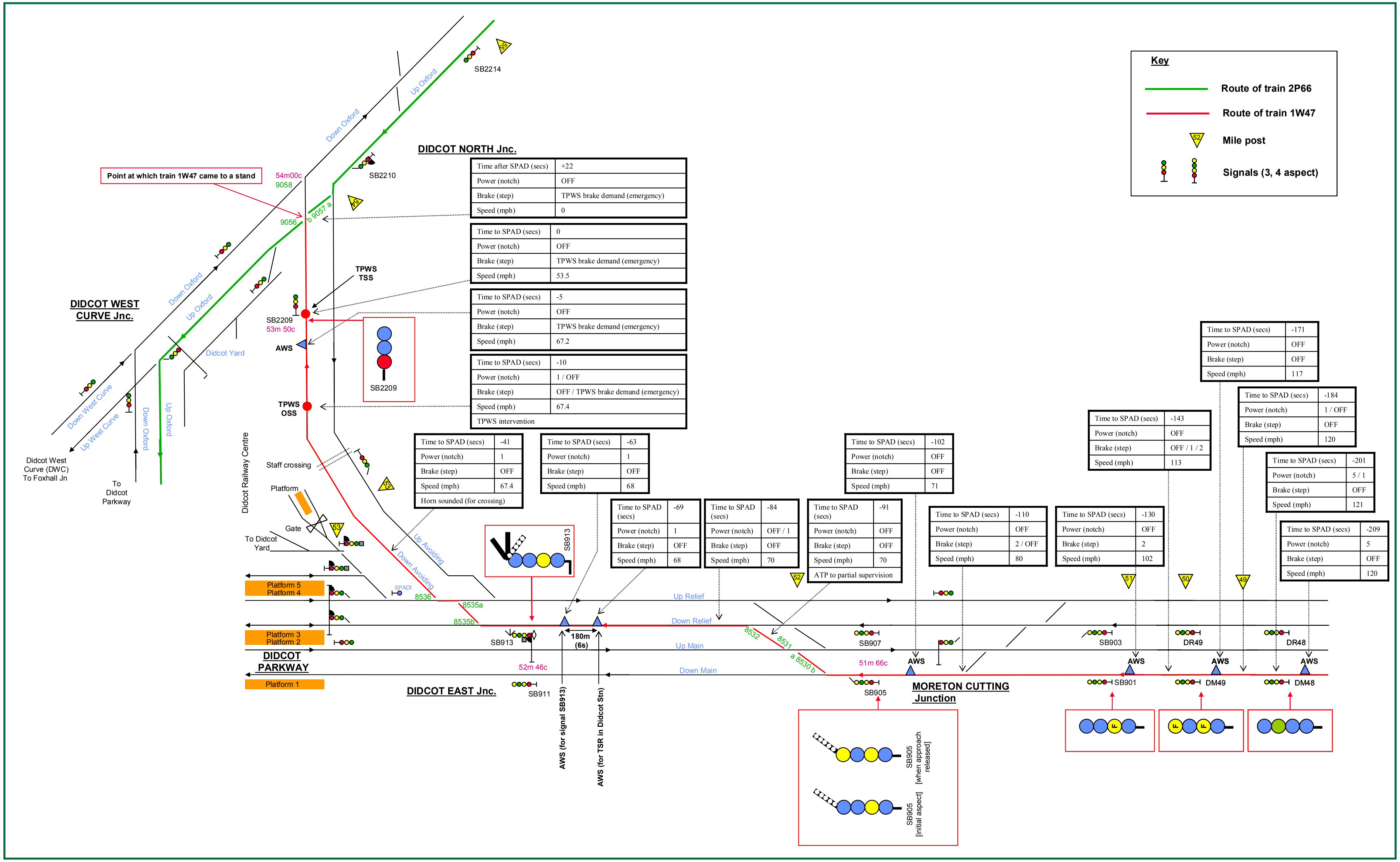
Appendix C - Detailed sequence of events

Time to SPAD (secs)	Event	Status of controls and speed of train 1W47			
		Power (notch)	**Brake** (step)	**Speed** (mph)	**Speed** (km/h)
-240	Automatic Route Setting sets route for train 2P66 into Didcot Parkway station via the Up Oxford line. Consequently, signal SB2210 clears from red to yellow (with the position 4 junction indicator illuminated) for the approach of train 2P66 (train 2P66 is approaching Appleford station). Signal SB2214 aspect changes from yellow to flashing yellow.				
-209	Train 1W47 passes Automatic Warning System (AWS) magnet of signal DM48. DM48 is showing green.	5	OFF	120	193
-201	About 250 m after passing DM48 the driver of train 1W47 reduces power.	5 ➔1	OFF	121	195
-200	Automatic Route Setting sets route for train 1W47 from signal SB905, on the Down Main line, towards SB2209 via Moreton Cutting junction and the Down Avoiding line. Consequently, signal SB905 clears from red to yellow (with the position 4 junction indicator illuminated) and SB913 clears from red to yellow (with the position 6 junction indicator illuminated) for the approach of train 1W47. Signal SB2209 remains at red (due to conflicting route set for train 2P66 ahead).				
-184	On approach to signal DM49 the driver of train 1W47 removes power.	1➔OFF	OFF	120	193
-171	Train 1W47 passes AWS magnet of signal DM49. DM49 is showing double flashing yellow. AWS warning horn sounds and AWS immediately cancelled.	OFF	OFF	117	188
-143	On approach to signal SB901 the driver of train 1W47 applies the brake.	OFF	OFF➔1➔2	113	182
-130	Train 1W47 passes AWS magnet of signal SB901. SB901 is showing single flashing yellow. AWS warning horn sounds and AWS immediately cancelled.	OFF	2	102	164
  -110	The aspect of signal SB905 changes from yellow (with the position 4 junction indicator illuminated) to double yellow (with the position 4 junction indicator illuminated). The driver of train 1W47 releases the brake (train 1W47 is about 520 m from signal SB905).	OFF	2➔OFF	80	129
-105	Train 2P66 passes signal SB2214 (which is displaying a flashing yellow aspect)				

Time to SPAD (secs)	Event	Status of controls and speed of train 1W47			
		Power (notch)	**Brake** (step)	**Speed** (mph)	**Speed** (km/h)
-102	Train 1W47 passes AWS magnet of signal SB905. SB905 is showing double yellow (with the position 4 junction indicator illuminated). AWS warning horn sounds and AWS immediately cancelled.	OFF	OFF	71	114
-91	Train 1W47 is traversing the crossover at Moreton Cutting junction. Automatic Train Protection automatically switches to partial supervision mode.	OFF	OFF	70	113
-84	Front cab of train 1W47 is clear of Moreton Cutting junction. Driver reapplies power.	OFF➔1	OFF	70	113
-69	Train 1W47 passes AWS magnet for Temporary Speed Restriction in Didcot Parkway station (not applicable to the route via the avoiding line). Horn sounded and AWS immediately cancelled.	1	OFF	68	109
-63	Train 1W47 passes AWS magnet of signal SB913. SB913 is showing single yellow (with the position 6 junction indicator illuminated). Horn sounded and AWS immediately cancelled.	1	OFF	68	109
-55	Signal SB2210 steps up from yellow to green (with the position 4 junction indicator illuminated).				
-41	Driver of train 1W47 sounds horn on approach to staff crossing.	1	OFF	67.4	108
-30	Train 2P66 passes signal SB2210 (which is displaying a green aspect with the position 4 junction indicator illuminated).				
-10	Train 1W47 passes TPWS over speed sensor loops and train brakes are automatically applied (emergency mode).	1➔OFF	OFF➔EMERG	67.4	108
-5	Train 1W47 passes AWS magnet of signal SB2209. Horn sounded and AWS cancelled by the driver within one second.	OFF	EMERG	67.2	108
-1	The back of train 2P66 clears the fouling point of 9056 points at Didcot North junction.				
0	Train 1W47 passes SB2209 at danger.	OFF	EMERG	53.5	86
+12	Train 1W47 reaches the fouling point of 9056 points.	OFF	EMERG	23	37
+22	Train 1W47 comes to a stand about 12 m beyond the crossing of 9056 points.	OFF	EMERG	0	0

Table C1: Sequence and timing of key events (see also Appendix D)

Appendix D - Overview diagram showing railway infrastructure and key events



Appendix E - History of the Train Protection Warning System (TPWS)

1 TPWS was originally conceived as a development of AWS by a joint British Rail and Railtrack working group in 1994 after it had been concluded that the nationwide installation of full Automatic Train Protection was not reasonably practicable.

2 The development of TPWS culminated in successful trial installations of track side and train mounted equipment during 1997. Trials and development continued during 1998 and 1999.

3 New regulations, the Railway Safety Regulations 1999, came into force on 30 January 2000. They required that train stops be fitted at a number of types of location. These included stop signals, the passing of which could cause a train to collide with another train. The regulations also required that associated 'speed traps' (i.e. over-speed sensors) be provided to prevent signals being approached at an excessive speed.

4 Railtrack commenced the wide-scale installation of TPWS track side equipment, and train operators commenced modifications of train mounted systems, in the early part of 2000.

5 In January 2001 a report was issued reporting the findings of the joint inquiry into TPWS chaired by Professor John Uff QC FREng and the Rt Hon Lord Cullen QC. This joint inquiry had arisen out of the perceived need for an independent review of the train protection issues arising out of the fatal collisions that occurred at Southall in September 1997 and at Ladbroke Grove in October 1999. The inquiry had taken evidence from witnesses and experts and was also informed by an independent report prepared by Sir David Davies CBE FREng FRS.

6 The Joint Inquiry report, and the report by Sir David Davies, both recognised that TPWS had a number of limitations. In particular, the reports recognised that a significant proportion of the trains in service at the time, including HSTs, had braking performance below that assumed in the design of TPWS.

7 The Joint Inquiry report was supportive of the already mandated installation of TPWS and recommended that this should continue. However, this support was given on the basis that TPWS would provide a relatively cheap, and quickly available, stop-gap prior to the wide-scale installation of the Automatic Train Protection.

8 The Joint Inquiry report also recommended that the scope of installation of TPWS should be informed by an assessment of risk at each location.

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