Rail Accident Investigation Branch

Rail Accident Report

Derailment near Liverpool Central underground station
26 October 2005

Department for Transport

Report 14/2006
August 2006

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 an investigation by the Rail Accident Investigation Branch (RAIB) is to prevent future accidents and incidents and improve railway safety.

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

3 Appendices at the rear of the report contain Glossaries explaining the following:

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

Summary

Key facts about the accident

4 At 17:41 hrs on 26 October 2005, train 2W43, the 17:06 hrs Merseyrail passenger train from West Kirby to West Kirby, via Liverpool Lime Street, derailed about 200 m on the approach to Liverpool Central underground station in Network Rail's London North Western Territory. Figure 1 below shows the route taken by the train.

5 The train was formed of a three-car class 508 *electric multiple unit* that operated from a *conductor rail* at 750 Volts DC (the 'third rail'), and the last bogie of the train derailed. The signalling of generally *two-aspect colour light* signals was controlled from the *integrated electronic control centre* (IECC) at Sandhills, with train detection being provided by *axle counters*.

6 The emergency services reached the train at about 18:25 hrs, and the subsequent evacuation of passengers took about 55 minutes to achieve.

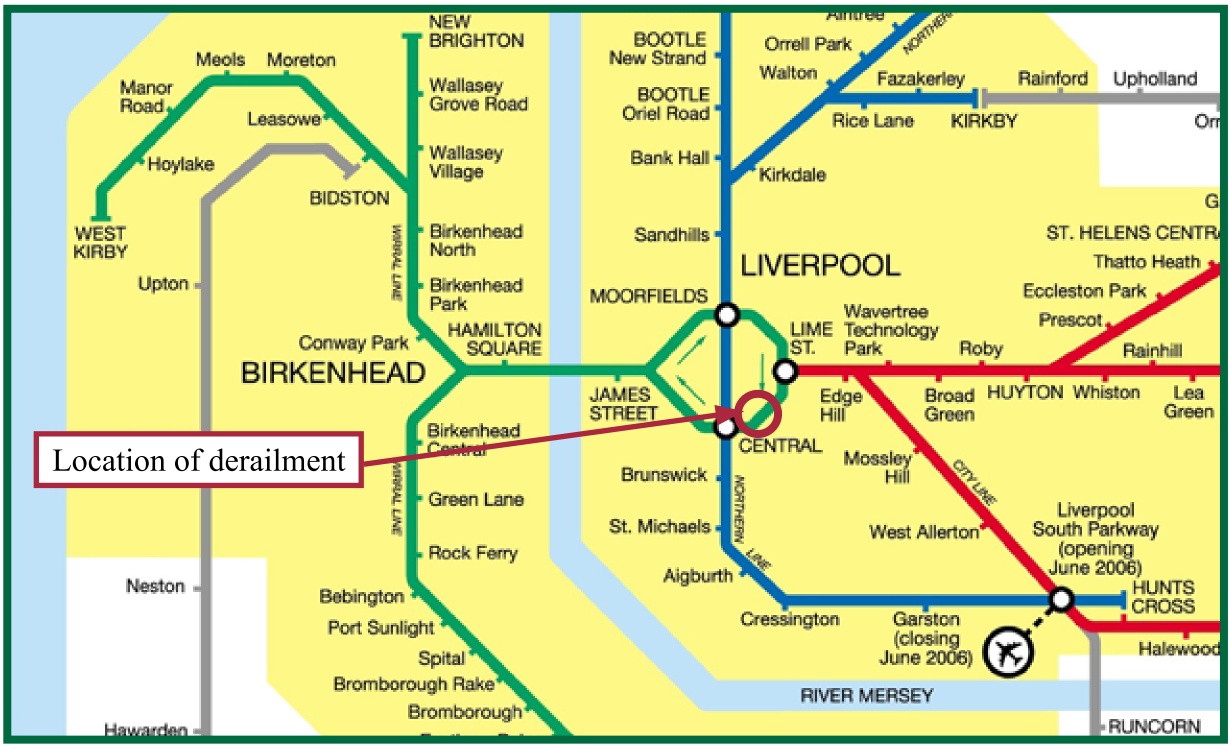


Figure 1: Extract map of the Merseyrail network (by courtesy of Merseyrail)

Immediate cause, causal factors and contributory factors

7 The immediate cause of the derailment was the widening of the *track gauge* during the passage of the train because the track was in poor condition. Attempts had been made previously to control the gauge between Liverpool Lime Street and Central Stations by fitting *tie-bars* and additional *baseplates* at intervals. These were ineffective in preventing the derailment.

8 Causal factors were the following:

- a maintenance system that was not matched to the degree of wear arising from the interaction between the trains and the track resulting in deteriorating track condition over time;
- deficiencies in the system of track inspection;
- inadequate maintenance of the track pending a planned renewal that should ideally have been carried out earlier in the asset's life;
- inadequacy of the rail fastening system;
- inappropriate use of tie-bars to maintain the gauge;
- a design that had not required the fitment of any *check rail* to the inside rail (*low rail*) of the curve.

9 Contributory factors were the following:

- resources in Network Rail's Merseyrail track maintenance engineer's organisation may not have been properly matched to the maintenance workload arising;
- there was no regular programme to clean the track formation to remove corrosive substances from around the rail foot and track fastenings.

Severity of consequences

10 The derailment occurred at low speed and caused only minor damage to the rolling stock and the infrastructure.

11 There were no immediate injuries to the 119 passengers or traincrew, although the guard subsequently attended hospital but was not detained.

Key conclusions

12 A systems approach to the train and track interface had not been adopted, with the result that the maintenance regime applied was insufficiently robust to cope with the deteriorating conditions of the Liverpool Loop line over a long period of time.

13 An assessment of the risks arising from the interaction between the trains and the track would have provided a sound basis for implementing a suitable maintenance regime with adequate resources.

14 When the emergency services reached the train, the evacuation of the passengers was carried out efficiently.

Recommendations

15 Recommendations can be found at paragraph 200. They relate to the following areas:

- a maintenance regime matched to the interaction between the trains and the track;
- the competence of track maintenance staff;
- ensuring sufficient resources are provided;
- the use of tie-bars to control track gauge;
- cleaning the trackbed;
- improving the emergency lighting system fitted to the class 507 and 508 trains.

The Accident

Accident description

16 The accident occurred at 17:41 hrs on 26 October 2005, when the rear bogie of train 2W43, the 17:06 hrs Merseyrail passenger train from West Kirby to West Kirby, via Liverpool Lime Street, derailed in the single bore tunnel, 222 m on the approach to Liverpool Central underground station. The train was running at only 12 mph (19 km/h) when the leading wheelset of the last bogie derailed. This occurred when the right hand wheel, seen in the direction of travel dropped down the *gauge face* of the rail due to the spreading of the gauge (*gauge spread*), and the left hand wheel subsequently climbed over the left hand rail. The following wheelset of the same bogie was subsequently dragged into derailment. Appendix D shows the final position of the rolling stock after the derailment occurred.

17 The permissible speed on the Liverpool Loop line was 30 mph (48 km/h), but, at the time of the derailment, a longstanding 20 mph (32 km/h) *temporary speed restriction* (TSR) was in force between Lime Street and Central stations because of Network Rail's concerns about the condition of the track. The TSR had been removed several times as work was carried out but had been subsequently reapplied as the track deteriorated further. Most recently, on 14 October 2005, the TSR had been re-imposed following the failure of some tie-bars.

The parties involved

18 The train concerned was operated by Merseyrail Services Holdings Ltd ('Merseyrail'). Merseyrail is one of two passenger franchises operated by a joint consortium of Serco Integrated Transport and Ned Railways, the Dutch railway operator. The train was crewed by a driver and guard.

19 The maintenance of the track was the responsibility of Network Rail.

Location

20 The section of single track underground railway between Liverpool Lime Street and Liverpool Central is part of the railway that is denoted by Network Rail as *Engineer's Line Reference* MIR1. This includes the Liverpool Loop tunnel and the Mersey Railway tunnel. The Liverpool Loop tunnel is 1 mile 1705 yards long, and Liverpool Central station is located at 1 mile 1054 yards, 914 yards from Liverpool Lime Street underground station, which is at 1 mile 140 yards. The line's normal permissible speed is 30 mph (48 km/h) and the Equivalent Million Gross Tonnes per Annum (EMGTPA) is 6. It is classified by Network Rail as *Track Category 4* in their system that determines, for example, the frequency of track inspections.

External circumstances

21 The accident occurred in tunnel where an ambient temperature of about 20°C is the norm.

22 Water ingress is a continual problem, exacerbated by the rising water table since the 1980s. When the line was built, the level of the water table was below the level of the tunnels but the amount of water extracted from the ground was reduced as manufacturing industry in the Liverpool area decreased. This caused the water table to rise above the level of the tunnels making them much wetter.

The track infrastructure

23 The Liverpool Loop line runs in a loop from Mann Island Junction, near James Street station, back to Mann Island Junction, through what is known as the Liverpool Loop tunnel (the Loop) on the Wirral Line. Liverpool Central station also has separate underground platforms on the line from Hunt's Cross to Southport, Ormskirk and Kirkby known as the Northern Line. This part of the station was not affected by the derailment. Appendix C shows the location.

24 The Loop was opened in 1977 as part of major changes to the suburban railway network in Liverpool. This included the construction of the Loop on the Wirral Line and the linking of the separate line to Garston, on the south side of Liverpool, to the lines on the north side running to Southport, Ormskirk and Kirkby. Trains on the Loop run clockwise from James Street station, returning back to James Street station, after calling at Moorfields, Lime Street and Central stations.

25 The tunnel contains single track of a design radius of 210 m curve radius and 50 mm *cant* and with a design gauge of 1435 mm on straight sections, 1438 mm on the transition curves and 1444 mm on the circular curve sections. The track consisted of flat bottomed 113 lb per yard rail fastened to pre-stressed concrete sleepers, manufactured by Costain, with *Pandrol clips*. There was no check rail fitted. The sleepers incorporated slots on the main vertical surfaces towards the ends of the sleepers to key with a surrounding concrete bed.

26 The railway is electrified using a separate conductor rail, outside the main running rails, energised at 750 V DC.

27 An open drainage channel ran along the track bed in the four-foot of the track. This was of sufficient breadth and depth as to cause the mid-sections of the sleepers to be unsupported. Metal plates were used to bridge the gaps in the sleeper bays and to form a walkway in the track. When first built, the drain was fully enclosed and covered by ballast between the concrete haunches supporting the sleepers and the running rails. The ballast was removed and the drain was opened out, due to the water table rising, during the 1980s (see paragraph 22).

28 The track in the Loop tunnel is in a very aggressive environment because of the ingress of water, dirt and *stray currents*. This caused corrosion of the rail foot and of the adjacent *housings* in the sleepers in which the Pandrol clips were fitted, compromising gauge. In addition, because of the tight radius of the curve and the suspension characteristics of the class 507 and 508 trains using it, the *high rail* wears rapidly on the gauge face (*sidewear*) necessitating renewal, on average, every six years.

29 To reduce the rate of sidewear (and, commensurately, the rate of wear of wheel profiles on the trains), a *flange lubricator* was provided on the high rail at the Lime Street station end of the curve between Lime Street and Central.

The train

30 The train consisted of a three-car class 508 electric multiple unit, number 508124, constructed between 1979 and 1980 by British Rail Engineering Limited (BREL) at their York workshops. It has subsequently been refurbished by Merseyrail. All axles were motored on the two outer vehicles, whereas the intermediate vehicle was unpowered. The details are shown in Table 1.

Vehicle No.	64672*	71506	64715
Designation	DMSO	TSO	BDMSO
No. of seats	59+1W	74	59+1W
Mass	36 tonnes	26.5 tonnes	36.5 tonnes

Table 1: Details of the train involved in the derailment

(Note*: 64672 was the leading vehicle)

31 The vehicles had steel underframes and bodies of aluminium alloy. Overall dimensions of each vehicle were 20.18 m by 2.82 m. BX1 bogies were fitted, designed by British Rail and built by BREL.

The signalling

32 Trains on the Loop are controlled by the IECC at Sandhills. This controls several *solid state interlockings* (SSI); the Loop being controlled by the James Street SSI. Signals are generally two-aspect colour lights, and the line has continuous train detection through the use of axle counters. *Trainstops* are provided at stop signals that would apply the brakes on any train that passed a signal at danger.

Events preceding the accident

33 The driver and guard for train 2W43 booked on duty at the traincrew depot at Birkenhead Central at 16:12 hrs. They then worked the 16:52 hrs train, composed of unit number 508124, from Birkenhead North station to West Kirby. Here, the train reversed its direction and took up its next working, the 17:06 hrs departure, reporting number 2W43, back to West Kirby via the Loop.

34 The subsequent journey was normal until the train was running between Liverpool Lime Street and Central stations. The train left Lime Street station at the correct time, and the driver accelerated to 20 mph (32 km/h), the maximum speed permitted by the TSR that extended to Central station.

35 The repair book on unit 508124 contained an entry made by a driver, on 22 October 2005, relating to ‘squeaking’ *anti-roll bar bushes* under car 64672, the DMSO that had given rise to a passenger complaint. These were subsequently lubricated at the maintenance depot on the day before the derailment and are known to be an issue on class 507 and 508 units.

36 A passenger during an earlier part of the journey leading to the derailment had also reported noise and vibration from the last bogie of the train (under car 64715, the BDMSO), when passing over pointwork, as the train left West Kirby. When the vehicle was examined, nothing was subsequently found to explain this, so it is surmised that the noise and vibration the passenger experienced may also have arisen from the anti-roll bar bushes.

Events during the accident

37 Between Lime Street and Central stations, as the train was already starting to slow for the station stop and running at only 12 mph (19 km/h), the driver felt the emergency brake apply automatically, some juddering and saw smoke go past the cab windows. The guard, who was travelling in the rear cab, felt the effects of the derailment to a much greater extent and was flung about the cab. The train came to rest about 200 m before the platform at Liverpool Central station, following the emergency brake application. Figure 2 shows the path taken by the derailed train following its derailment and some of the fitted tie-bars.

Figure 2: View of the rear of train 2W43 following its derailment (courtesy of British Transport Police)

Fatalities, injuries and material damage

38 None of the passengers were injured as a result of the derailment. The driver was also uninjured; however, the guard attended hospital during the night following the derailment but was not detained.

39 Damage to the train, as a result of the derailment, was limited and consisted of damage to wheel surfaces, a damaged *gearcase* and *tripcock*.

40 The damage to the track was also limited and consisted of damage to sleepers and fastenings over a 30 m distance.

Events following the accident

41 Following the derailment, the guard spoke to the driver from the rear cab and confirmed that the train was derailed. The driver made an emergency call on the *cab secure radio* to the signaller at Sandhills IECC to ask for an emergency isolation of the electrical supply to the conductor rail and to confirm that the train was protected from other trains. Following confirmation that the electrical supply was isolated, the traincrew placed *short circuiting bars* between the conductor rail and the adjacent running rail, one at each end of the train, to ensure that there was no possibility of the conductor rail being re-energised.

42 The signaller at Sandhills IECC arranged for the emergency isolation to be given, ensured signals behind the derailed train were at danger and advised the signalling centre supervisor who called the emergency services.

43 Network Rail appointed a Rail Incident Officer, who facilitated access by the emergency services into the tunnel at 18:20 hrs, in order to commence the evacuation of the passengers. This was started at 18:30 hrs through the end front door of the train and down the emergency step ladder provided for this purpose. Passengers were evacuated five at a time, and the evacuation of all 119 passengers plus the two traincrew to the platform at Liverpool Central station was completed by 19:20 hrs.

44 Pending the arrival of the emergency services, the driver and guard went through the train regularly to reassure the passengers and advise them what was happening. Twenty minutes after the derailment, the train emergency lights went out because the battery life had expired. After this, the only lighting was provided by the lights installed throughout the tunnel.

The Investigation

Investigation process

45 Following the accident, both the Merseyside Police Force and the British Transport Police (BTP) attended. The BTP subsequently maintained and controlled access to the site through the inner cordon at street level to the Loop line platform.

46 On arrival, inspectors from the RAIB liaised with both Merseyside Police and the BTP, and it was immediately agreed that the RAIB should lead the investigation into the derailment. Good co-operation was obtained from the BTP, including by crime scene officers who readily gave assistance to the RAIB by making a photographic record of site conditions.

47 The RAIB also liaised with Her Majesty's Railway Inspectorate (HMRI) both on site and during the course of the investigation with good co-operation on both sides.

48 Good co-operation was also obtained from Network Rail and Merseyrail throughout the RAIB's investigation.

Sources of evidence

49 In carrying out the investigation of the derailment of train 2W43, the following sources of evidence were used:

- Interviews with staff in Merseyrail concerning train running; the occurrence of the derailment; the evacuation of the passengers, and the maintenance of the train, including issues such as wheel wear.
- Interviews with staff in Network Rail concerning the method of identifying defects in the track, prioritising them and repairing them. Also, the range of maintenance problems experienced and methods to combat them; flows of information; the criteria for renewals; the resources available; compliance with track maintenance standards, and how performance was judged.
- Maintenance records for the section of line where the derailment occurred; including the outputs from the regular runs carried out by the *track recording train*.
- The output from the data recorder fitted to the train showing how the train was driven between Liverpool Lime Street and Liverpool Central stations.
- The output from the tapes recording the operation of the signalling equipment between Liverpool Lime Street and Liverpool Central stations.
- The output of the voice tapes that recorded the safety critical communication between the driver of train 2W43 and the signaller at Sandhills IECC shortly after the derailment occurred.
- The output of the recordings made by the in-train CCTV camera prior to and following the occurrence of the derailment.

50 In addition, use was made of the photographs taken by the RAIB inspectors on site, together with all other records made during the investigation on site.

Key evidence

51 The *Point of Derailment* (POD) was measured at 392 m (429 yards) from the *headwall* of Lime Street station, located at 1 mile 204 yards. The POD was therefore at 1 mile 633 yards. Both before and after the POD, the track condition was found to be poor, with loose Pandrol clips due to corrosion or wear, and broken or missing *insulators*. There were many tie-bars fitted, including five that had broken. At the POD, a tie-bar had previously failed at the left hand end retaining lug. Figure 3 shows the track in the vicinity of the derailment and tie-bars that had been fitted just after the POD.

Figure 3: Tie-bars fitted to the track close to where the derailment occurred (courtesy of British Transport Police)

52 Both the right hand rail (the low rail) and left hand rail (the high rail) showed evidence of movement ('shuffling') away from the track centre-line (see Figure 4). This was greatest where rail insulators were either broken or missing.

53 There was evidence of sidewear of the high rail, and this was found to be 6 mm at the point of derailment. Although significant, the sidewear was within maintenance limits. The degree of sidewear of the high rail at the POD can be seen in Appendix E.

54 The trackbed around the rail foot and the housings for the Pandrol clips was heavily contaminated with detritus, causing corrosion of the rail foot over time, resulting in loss of width and depth as well as corrosion of the housings. Figure 5 shows the degree of contamination and also areas of track marked up by the maintainer for further tie-bar fitment, which was not carried out before the derailment occurred.

55 The track was surveyed from 115 sleepers before the POD to 24 sleepers after it. In addition, rail profiles at 12 locations were measured, the wheel profiles were measured, and *gauge spreading tests* were carried out.

Figure 4: Sleeper 105 showing the degree of rail shuffle that had taken place (note the missing Pandrol clip)

Figure 5: Showing the degree of contamination around housings and locations marked for further fitment of tie-bars

56 The results of the measurements taken on site were used in the subsequent *Vampire*® modelling work, described later in paragraphs 94 to 126.

57 Table 2 below shows the track parameters at the POD. The average curve radius over the survey distance to the POD was 204 m

Curve radius	170 m
Cant	47 mm
Gauge	1465 mm
Unloaded *cant gradient*	zero

Table 2: Track parameters at the POD

Note: the value for cant is unlikely to have changed since the line was built, and the maintenance limits for *static gauge* are 1450 mm at the permissible line speed of 30 mph (48 km/h), and 1455 mm at the TSR value of 20 mph (32 km/h). A more complete explanation of the maintenance limits is in Paragraph 66.

58 For the rolling stock, the wheel profiles and the *wheelset back-to-back dimensions* of the bogie that derailed were measured. The flange height and thickness measurements for the wheels of the derailed bogie were within maintenance limits (maximum 36.5 mm flange height, minimum 24 mm flange width). The details are shown in Table 3.

Wheel	**Flange height (mm)**	**Flange width (mm)**
Right leading	30	28
Right trailing	30	27.5
Left leading	30	25
Left trailing	30	26

Table 3: Wheel flange height and thicknesses of those that derailed

Note: for each wheelset, the wheelset back-to-back dimensions were measured at three locations and the results are shown in Table 4. Two of the measurements were slightly outside maintenance limits (1360 - 1365.5 mm) but the difference is not significant.

Position	**1**	**2**	**3**
Leading wheelset	1361 mm	1360.5 mm	1360 mm
Trailing wheelset	1360 mm	1359.5 mm	1359.5 mm

Table 4: Back-to-back dimensions of the derailed wheelsets

Other evidence findings

59 Predominantly due to sidewear, rail fitted to the Liverpool Loop has to be renewed every six years on average (and, in some cases, in as little as every three years). In the area where the derailment occurred, the rail was last renewed on 3 August 2003.

60 In order to remove the build up of corrosive contaminants from around the rail foot, the track used to be jet-washed. However, this had not been carried out on a regular basis for some time, and the last time any jet washing was carried out was in July 2004.

61 On some sections of the Loop, housings had been renewed over a period of several years from about 1998, and intermediate baseplates between housings had also been fitted since 2001. However, these were jobs that Network Rail stated required specialist contractors to carry out and only a few were available to carry out this sort of work. Also, where housings were renewed, it was necessary to give sufficient time for the grout around the new housings to set before trains should run again. Network Rail's staff stated that this was not always given, with the result that new housings were pushed out of position, further compromising gauge. Housings for the high rail in the area where the derailment occurred had been renewed between 1998 and 2000.

62 Around the end of 2004, Network Rail sought the advice of Pandrol UK Ltd, the UK subsidiary of Pandrol Rail Fastenings Ltd, on the type of track fastening best suited to the tunnel environment. Pandrol advised the use of their *e-Plus clips*, in conjunction with *toe insulators* and *gauge management insulators* as a stopgap measure, pending complete renewal of the track. The e-Plus clips have the benefit of providing a high *toe load* on the rail foot, with the aim of preventing movement. Network Rail decided to fit e-Plus clips to the Loop, but they had not completed the programme of fitment between Lime Street and Central, and they had not been fitted where the derailment occurred. Figure 6 below shows fitted Pandrol e-Plus clips and gauge management insulators beyond where the derailment occurred.

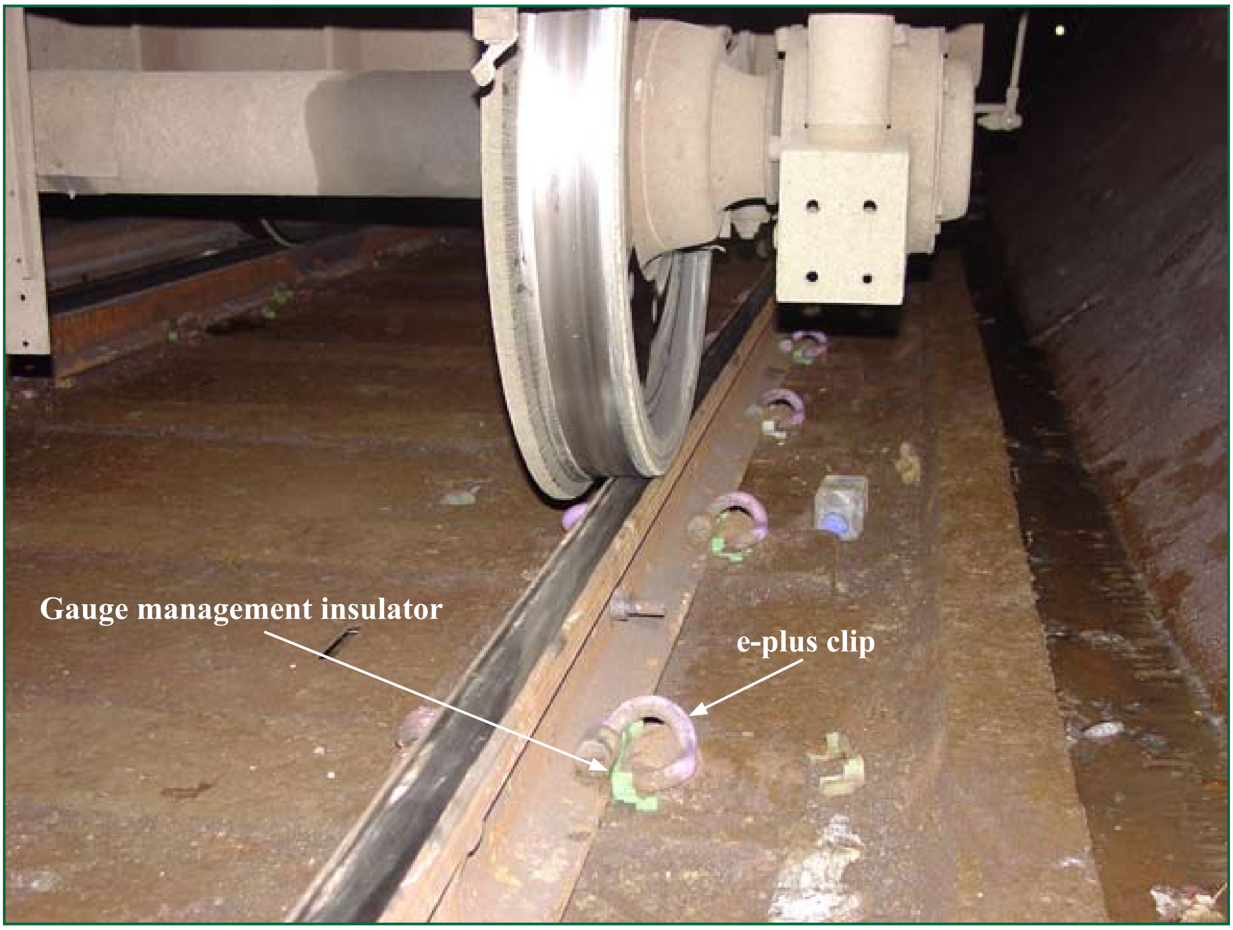


Figure 6: Pandrol e-Plus clips

63 Owing to the intensity of the train service, the time available to carry out work on the track in the Loop tunnel was limited to between 01:30 hrs and 04:30 hrs each night, although longer periods were available at weekends. There were also four 12 hour and four 29 hour possessions available each year for carrying out major works.

64 The section of track between Lime Street and Central stations was planned for renewal in early 2006/7. This was as a result of visits made by the Territory Track Engineer, shortly after a Network Rail reorganisation in May 2004, in which the Loop came under the new London North Western Territory. Prior to that, and when the maintenance was the responsibility of a contractor, no formal renewals proposal was ever submitted.

65 The factors described above gave rise to significant problems for the maintainer in maintaining the gauge within maintenance limits. This led to the widespread use of tie-bars, with the aim of preventing further worsening of the gauge.

66 The maintenance limits were prescribed in Network Rail's standard RT/CE/S/104 in use at the time of the derailment. This stated that 'where static (ie unloaded) track gauge exceeds 1465 mm (1455 mm for speeds over 125 mph), or if it exceeds 1455 mm and there are signs of baseplate/chair movement on the sleepers, damaged screws or loose housings etc, steps shall be taken to restrain further gauge widening; *dynamic gauge* shall be measured where practicable; if this exceeds 1481 mm traffic shall be stopped immediately, until repairs have been carried out. These figures are based on a nominal track gauge of 1432 mm or 1435 mm and may be increased by any approved gauge widening.'

67 With designed gauge widening of 9 mm to 1444 mm in the circular curved sections of the tunnel the gauge at the POD, at 1465 mm, was 1 mm greater than the static limit for track with signs of movement (1455 + 9 mm allowance for gauge widening). Measures had been taken to address this in accordance with the standard by fitting tie bars.

68 Standard RT/CE/S/104, permitted the use of tie-bars, as a temporary measure, where gauge widening had occurred that was not part of the design. This was in the context that permanent repairs had to be carried out as soon a possible and, in any case, within six months. A register of the locations of tie-bars was required to be kept showing when they were fitted and then subsequently removed. These same requirements were carried forward into the new standard NR/SP/TRK/001 that has replaced RT/CE/S/104 (except that the time limit on the use of tie-bars in sidings has been relaxed to 12 months).

69 Many tie-bars fitted between Lime Street and Central were in place for much longer than the six months permitted by Network Rail's standard RT/CE/S/104. The Area Track Engineer had granted verbal dispensations against this requirement to the Track Maintenance Engineer, with an understanding that the use of tie-bars would be required until the track was completely renewed.

70 The register recording the fitment of tie-bars existed, but it was found to be inaccurate. However, it did record that tie-bars had been fitted (and not subsequently removed) between Lime Street and Central on the following dates:

- 25 fitted on 1/8/2003;
- 9 fitted on 10/9/2003;
- 4 fitted on 19/1/2005;
- 19 fitted on 23/2/2005;
- 9 fitted on 19/5/2005.

71 There was insufficient detail in the tie-bar register to tell whether the records in paragraph 70 include the tie-bar that had broken at the POD or those that had been fitted just after the POD.

72 Some of the tie-bars fitted had been used previously and so were already part way through their *fatigue life* and, therefore, more likely to break. RT/CE/S/104 did not prohibit the re-use of tie-bars.

73 In order to fit or remove tie-bars, the construction of the track necessitates each rail being lifted off its housings so that the lugs at each end of the tie-bar can be slid under the rails. This is because there is insufficient clearance between the underside of the rail and the concrete base for the lugs to pass. It has been the practice, therefore, to leave tie-bars in place but loosened off, even when not required to be fitted. There were no entries in the tie-bar register going back to July 2003 recording the removal of any tie-bars

74 The fitment of tie-bars also required the removal of some of the metal plates used to cover the drainage channel after it had been opened out (paragraph 27). This is evident in Figure 2.

Previous occurrences of a similar character

75 There had been no previous derailments in the Liverpool Loop tunnel.

76 However, there have been previous derailments to the almost identical class 507 electric multiple units on the Merseyrail network. On 4 May 1999, and again on 17 May 1999, unit 507024 derailed in the maintenance depot sidings at Birkenhead. The cause was excessive *track twist* and vehicle *torsional stiffness* that was slightly outside acceptable limits. The torsional stiffness had been aggravated by the fact that one of the *secondary air suspensions* was deflated. On 19 May 2004, unit 507009 derailed at a set of *facing points* as it approached Birkenhead North station, due to a worn and damaged *switch rail*, exacerbated by an imbalance in wheel loads across the vehicle that derailed.

77 It is not considered that any of the three derailments above has any significant relevance to the derailment in the Loop on 26 October 2005. However, all the derailments on 4 and 17 May 1999, and on 19 May 2004, were caused by factors in both the vehicle and in the track; an issue which is also relevant to the derailment on 26 October 2005.

78 The railway industry has carried out previous investigations into the interaction between the class 507 and 508 vehicles and the track following periods of high rates of wear of the wheel flanges and high rail sidewear. These investigations concluded that the cause was a gradual reduction in the effectiveness of a number of flange lubricators at critical locations.

Analysis

Identification of the immediate cause

79 The derailment occurred when the leading right hand wheel of the last bogie of the train partially descended down the gauge face of the low rail at a location where a tie-bar had previously broken. Initially, the lateral restraint provided by the track prevented the wheel from wholly dropping onto the trackbed or the track fastenings, and the left hand wheel remained in its normal running position, but with its flange in hard contact with the gauge face of the left hand high rail. Figure 7 shows the *tread corner* mark where the right hand wheel descended the gauge face.

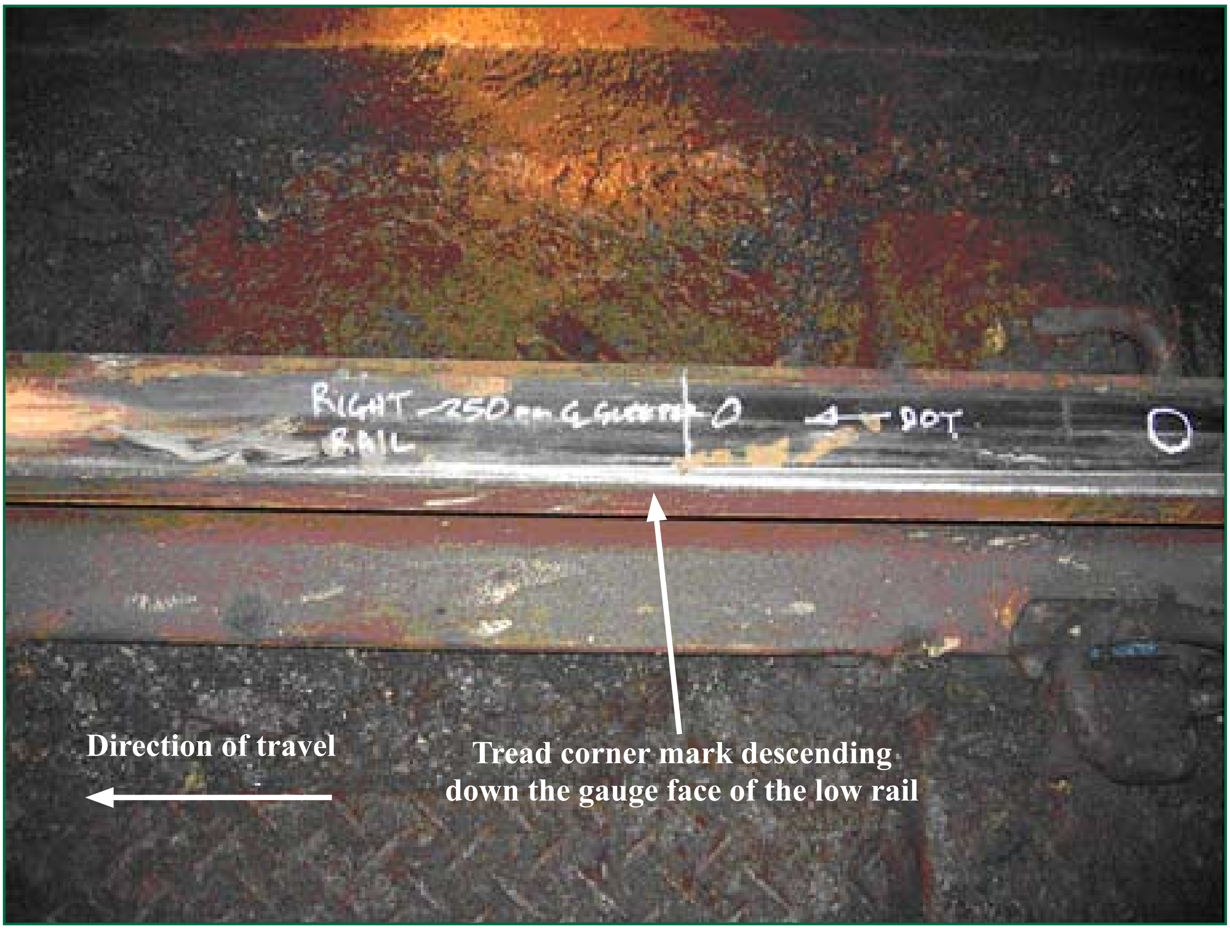


Figure 7: Tread corner marks descending down the gauge face of the right hand rail head

80 Figure 8 shows the situation that existed just as the derailment occurred. From the measurement of static gauge at the POD (1465 mm), and the wheelset dimensions that were measured, the gauge faces of the rails displaced by a further 51 mm (1516 mm – 1465 mm) as a result of the gauge spreading forces arising from the train.

81 Between the second and third sleepers beyond the initial POD, the flange of the left hand leading wheel of the trailing bogie climbed the gauge face of the high rail and, in doing so, relieved the high lateral *gauge spreading forces*. This allowed the leading right wheel of the trailing bogie to continue its descent down the gauge face of the low rail into full derailment between the third and fourth sleepers from the initial POD. Figure 9 shows the flange climb marks and Figure 10 shows the derailment of the right hand wheel.

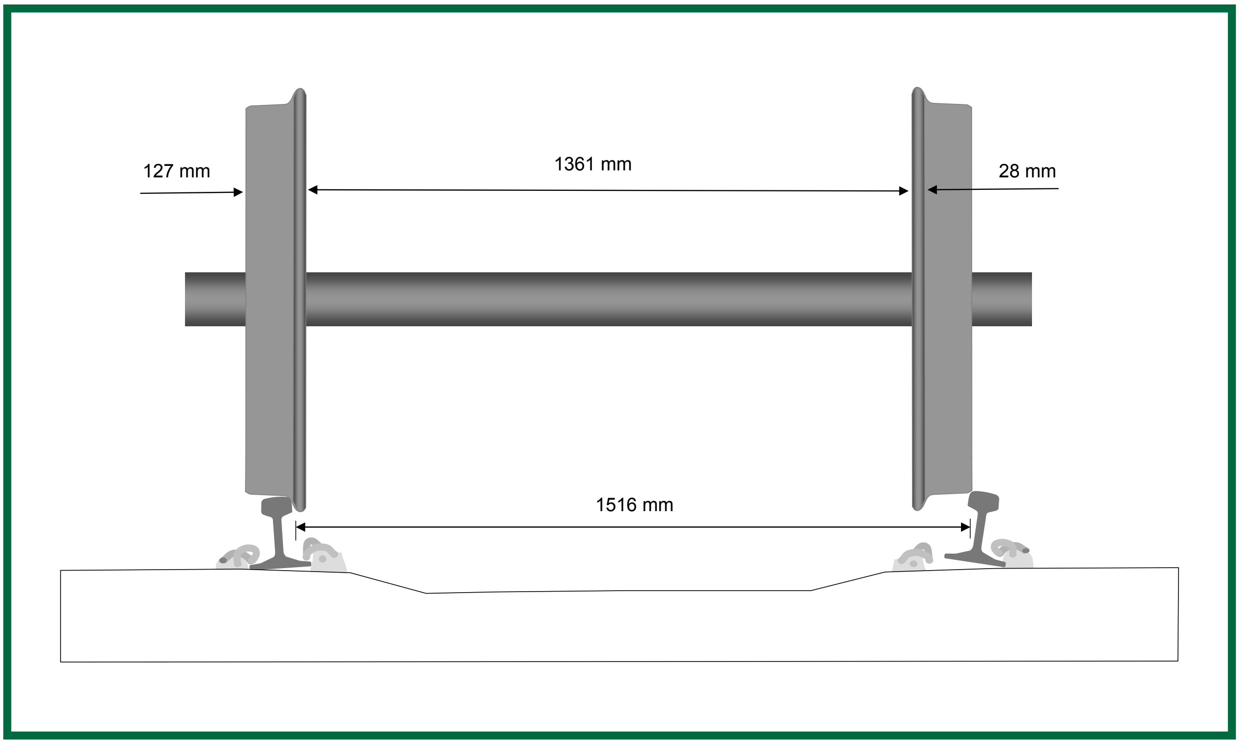


Figure 8: Diagram of critical gauge spread dimensions to cause derailment

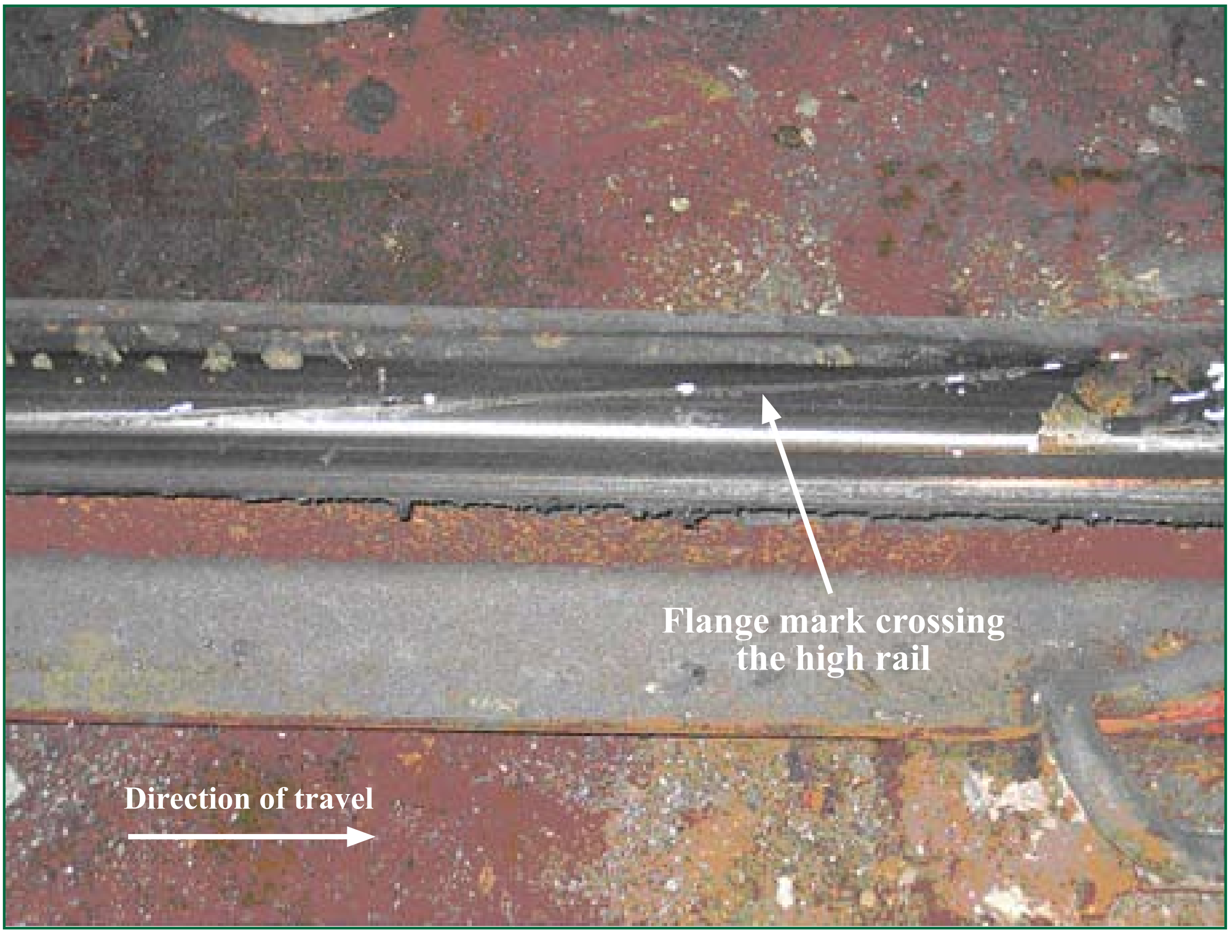


Figure 9: Flange climb mark up the gauge face of the high rail between the second and third sleepers

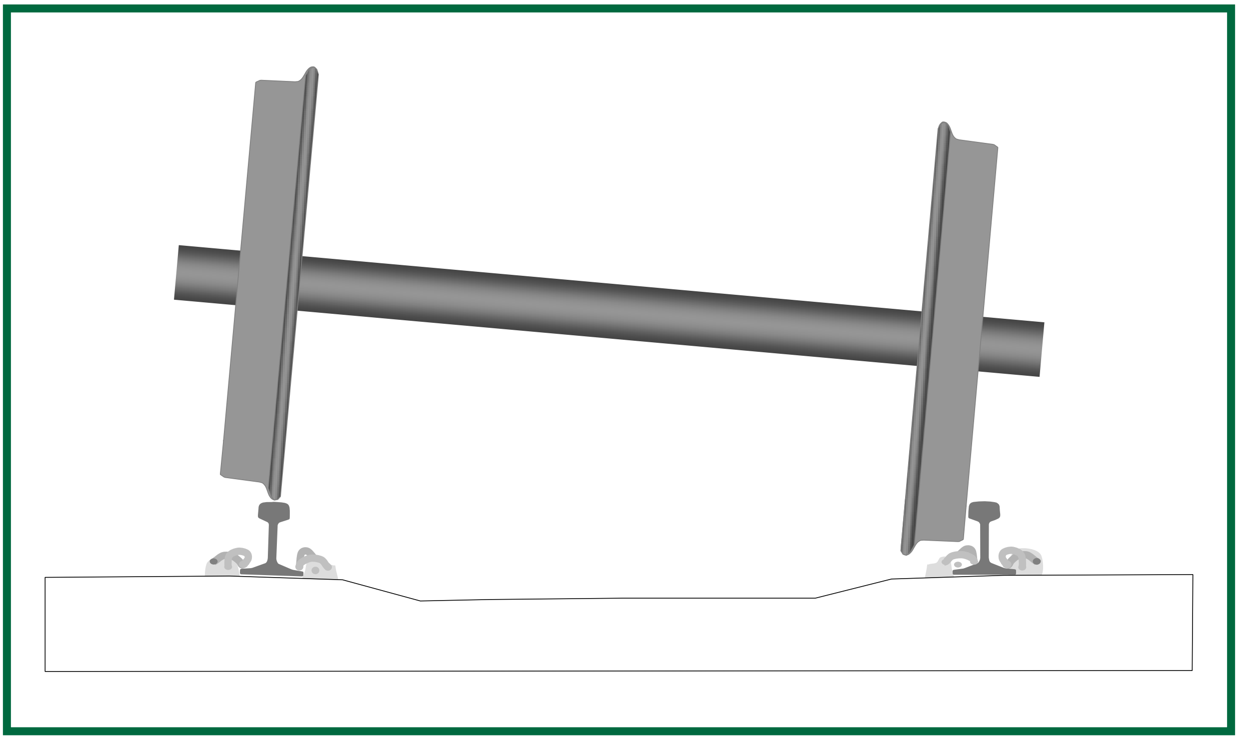


Figure 10: Diagram of wheelset showing how the left hand wheel has flange climbed onto the rail head allowing the right hand wheel to fully derail

82 The left hand wheel crossed the rail head and ran into full derailment to the left of the high rail, 100 mm before the leading edge of the fourth sleeper from the initial POD.

83 The wheelset continued to run derailed, contacting the track fastenings and sleepers, until the train was brought to a stand, having run about 30 m from the initial POD.

84 The trailing wheelset of the trailing bogie was dragged into derailment by the derailed leading wheelset, close to where the train finally came to rest.

85 From the foregoing, the immediate cause of the accident was the dynamic spreading of the track gauge during the passage of train 2W43.

Analysis of the derailment mechanism

86 It was found that a significant groove had developed on the head of the low rail in the vicinity of the POD. It commenced about two sleepers before the POD, approximately 15 mm from the gauge face and, as the groove progressed towards the POD, it migrated towards the gauge face such that, at the POD, it had reached the *gauge corner*. Beyond the POD, the groove migrated back across towards the *field side* so that, by two sleepers beyond the POD, it was 10 mm away from the gauge face. This *witness mark* was typical of that formed by the tread corners of wheels running on track that was wide to gauge. The groove, just before where the leading right wheel of the last bogie descended down the gauge face, is shown in Figure 11.

87 The rail profiles were measured, using a digital profile recorder and a paper trace profiler, at a number of sleeper locations on the approach to the POD, at the POD and at one location after it. For the POD (sleeper zero), these are shown in Appendix E. The profile of the low rail shows the groove referred to above.

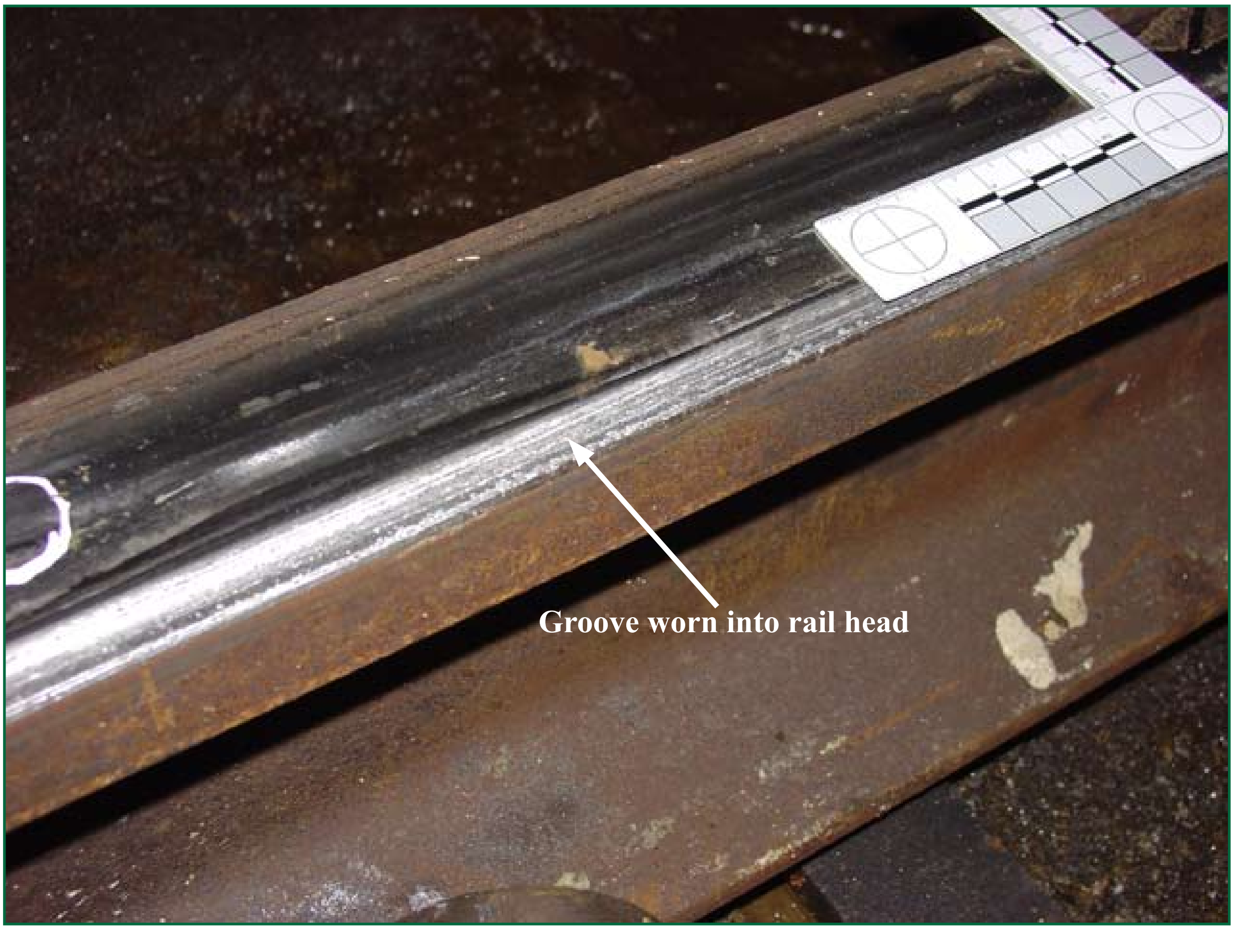


Figure 11: Groove on the low rail just before the point of derailment

88 Several gauge spreading tests were carried out to provide data for the subsequent Vampire® modelling work described from paragraph 94 to paragraph 126. The tests applied lateral gauge spreading forces between the inner faces of the rail webs, just below the rail head using a calibrated hydraulic ram. The gauge spreading force was applied incrementally and, at each increment, the gauge was recorded. The tests were carried out at the POD and at sleepers 5, 30 and 105 before the derailment (the results are plotted in Figure 12).

89 The gauge spreading tests were indicative only, given that the weight of a train was not present and the spreading force was applied below the rail head.

90 The tests showed that the lateral resistance of the rails was low with the static gauge measurement of 1465 mm (zero applied gauge spreading force) at the POD increasing rapidly to more than 1500 mm with a gauge spreading force of 33.05 kN. By way of comparison, the measured gauge at sleeper 105 was 1484.5 mm with the application of 33.05 kN gauge spreading force. The measurements made at the POD are shown in Table 5.

Gauge Spreading Force (kN)	Track Gauge (mm)	Total gauge spread (mm)
0	1465	0
8.5	1478	13
18.1	1487.5	22.5
28.1	1495	30
33.05	1502.5	37.5
35.05	1505	40
38.1	1506.5	41.5
48.1	1508	43
53.05	1509	44

Table 5: Results of gauge spreading tests at the POD

91 At the time of the derailment, the Network Rail Standard covering track inspection was RT/CE/S/103 'Track Inspection Requirements' (since replaced by NR/SP/TRK/001 with a compliance date of 1 January 2006). RT/CE/S/103 included the system of track inspection, the measurement of gauge and wide gauge. The maintenance limits applicable to gauge are described in paragraph 66.

92 On 20 October 2005, Network Rail measured the static gauge between Lime Street and Central at several locations, during an inspection to confirm the renewal planned for the year 2006 to 2007. At 1 mile 850 yards, static gauge was measured at 1460 mm and, closer to Lime Street, at 1 mile 550 yards, the static gauge was found to be 1453 mm, with another 10 mm of baseplate shuffle evident (note that from paragraph 51 the POD was at 1 mile 633 yards). Further tie-bars were to be fitted (Figure 5 shows a section of the track marked up for more tie-bars), but this was not completed before the derailment occurred.

93 The results of the gauge spreading tests were used in the subsequent modelling of the train/track interaction, in order to investigate further the mechanism of the derailment.

Study of the derailment using the Vampire® vehicle dynamics modelling package

94 A study of the derailment was carried out using the Vampire® vehicle dynamics modelling package that was developed by British Rail Research and, subsequently, by AEA Technology Rail (AEAT). It has been used previously in a large number of studies relating to derailment investigations and curving performance. The study was carried out in two parts:

- The construction of a computer model of the derailment as it occurred, in order to provide an understanding of the derailment mechanism in terms of gauge spreading forces and gauge spread. The model was developed using a series of simulations which considered trends associated with these gauge spreading effects. This helped to verify the conclusions reached as to the cause of the derailment determined from the observations made at the derailment site.
- A *parametric study* to show the effect on the risk of derailment of changing different factors. These included the track characteristics, vehicle suspension characteristics, train speed and rail friction levels.

95 Two vehicle models were used in the study:

- A representation of the class 508 motor car which derailed.
- A representation of a class 465 motor car, considered typical of a comparable more modern alternative train. This model was only used as part of the parametric study.

96 The track survey undertaken on site was used to define the track geometry inputs to the model.

97 The rail-sleeper *lateral stiffness* values used in the study were based on the gauge spreading tests carried out on site. The test measurements are plotted in Figure 12 and show a two stage non-linear characteristic – initially, the lateral stiffness is low, suggesting this phase is taken up by simple movement of the rail sideways on the baseplates ('shuffle'). This is particularly the case for sleeper zero (the POD) and sleeper 105, where relatively small gauge spreading forces give rise to significant gauge spread. The subsequent increased stiffness probably results once 'play' in the baseplates has been taken up and further widening can only occur due to outwards rotation of the rail. The rail-sleeper lateral stiffness values used in the computer model were obtained by linearising the measured characteristics plotted in Figure 12.

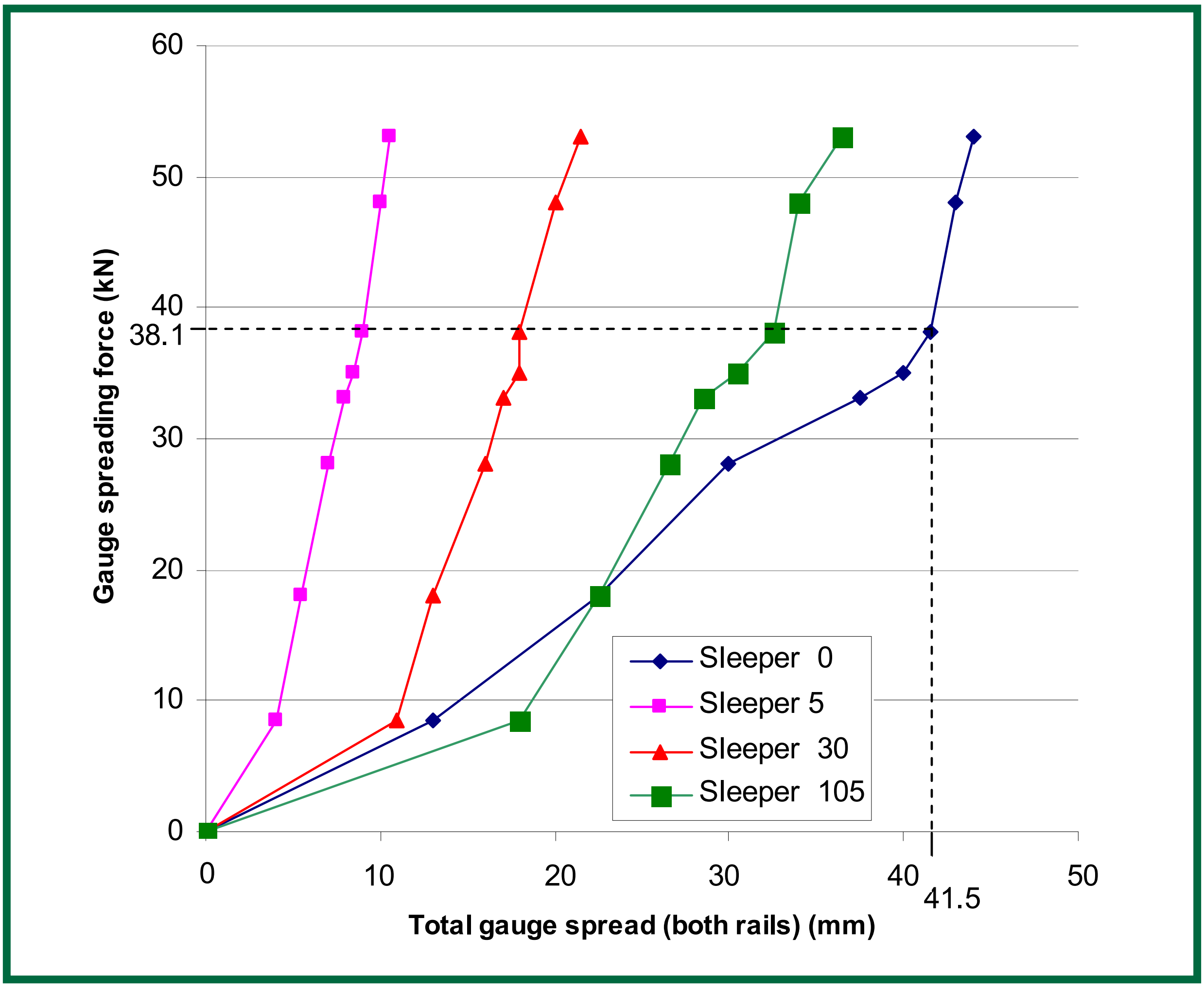


Figure 12: Gauge spreading test results obtained from the derailment site

98 The first simulation considered that the track gauge presented to each wheel of the derailed vehicle was the static gauge as measured after the accident. The results showed that, although maximum gauge spreading occurred in the vicinity of the POD, the gauge spread predicted by the Vampire® programme of 13.2 mm was not enough to cause the derailment to occur. It was concluded that the reason for this is that Vampire® assumes that gauge spread caused by one wheelset has no effect on that presented to following wheelsets. It was considered this assumption was probably invalid considering the low levels of rail-sleeper lateral stiffness measured and the amount of observed baseplate movement. It was likely that the forces imposed by preceding wheelsets could have prevented the rails returning to their unloaded (static) position before the passage of the next wheelset. The consequence of this was that the derailment risk could have increased with the passage of successive wheelsets in a train.

99 Further simulations were conducted to evaluate the above proposal. In the second simulation, the gauge was increased by the amount of gauge spread calculated to be due to the passage of the leading wheelset (13.2 mm found from the first simulation). The results predicted a total gauge spreading of 26.8 mm at the POD, which was still not sufficient to cause the third wheelset (the wheelset that actually derailed) to drop into the four-foot and so derail.

100 In a third simulation, the increase in gauge caused by the passage of earlier wheelsets was taken to be the initial slide that was possible of the rails on their baseplates. Referring to Figure 12, it can be seen that, for sleeper zero (the POD), the maximum slide on the baseplates was 41.5 mm for both rails, corresponding to a gauge spreading force of 38.1 kN. Beyond this point – the maximum extent of the relatively straight section of the graph – further gauge spreading can only occur by the rails rolling outwards.

101 The results of the third simulation gave a dynamic gauge spread of 8.8 mm and a maximum gauge spreading force of 43 kN. This gauge spreading force was greater than the values obtained from the first simulations, almost certainly because, as the gauge increased, the *angle of attack* of the wheelset increased. Combining this dynamic gauge spread with the 41.5 mm of possible movement of the rails on their baseplates, results in a total possible dynamic gauge spread of 50.3 mm at the POD.

102 Although just less than the 51 mm of gauge spread required to cause derailment (1516 mm – 1465 mm = 51 mm; see also Figure 8; 1465 mm being the static gauge measured on site – see Table 2), the calculated dynamic gauge spread of 50.3 mm would be sufficient to cause the derailment of the third wheelset. Also, given that the outside edge of the wheel was chamfered, the lateral force generated would be increased when the wheel and rail contact were within 5 mm of the right hand rail.

103 In summary, the simulation study helped to demonstrate the influence that the leading wheelsets had on the gauge presented to the following wheelsets. It showed that, on track having low rail-sleeper lateral restraint, preceding wheelsets progressively widen the gauge. The study helped the understanding of why it was the last bogie of the train that derailed.

104 The results of the subsequent parametric study are shown in the table in Appendix F and discussed in more detail below. The results are based on the initial gauge widening that occurred following the passage of the leading bogie (13.2 mm, the second simulation) and do not take account of further gauge widening due to the initial movement of the rails on their baseplates. This is referred to as the 'base case' in the table in Appendix F. The reason for this is that, because the second simulation did not predict derailment, it enables an assessment of both the improvement and worsening associated with the respective vehicle, track and operational changes. ââ

Effect of suspension modifications

105 The first part of the parametric study was to determine to what extent changes to the suspension characteristics of the class 507 and 508 units would reduce the gauge spreading forces and improve the vehicle's ability to curve. This was done by modelling different stiffness values of the primary trailing arm bushes used in the suspension of the class 508 units.

106 The study found that lower gauge spreading forces would occur by significantly reducing the stiffness of the *primary trailing arm bushes* used in the suspension of the class 507 and 508 units. However, it was considered that this alone would not represent a practical means of improving these existing vehicles as other major changes would be needed to achieve a functional design.

107 These findings reinforce the results of a study carried out by AEAT in 2000 into the causes of an increase in wheel flange wear and sidewear on the Merseyrail system (ie not just the Liverpool Loop). The report on this study describes trials with a modified primary trailing arm bush undertaken on the Merseyrail system which gave rise to unstable *hunting* on straighter, higher speed sections of the Merseyrail network. This illustrates the conflict faced by vehicle designers in that designing vehicles for good curving performance adversely affects stability and lateral ride quality. Radially steered bogies are designed to overcome this conflict, but it would be unlikely to be cost effective to fit such bogies to class 507/8 units.

108 The AEAT 2000 study is discussed further in paragraphs 129 to 131.

109 This report describes earlier (paragraphs 35 and 36) how noise had been heard from the anti-roll bar bushes. This suggested a possible deterioration in anti-roll bar stiffness. The effect of the anti-roll bars was included in the parametric study to investigate whether they had any significance at all in the cause of the derailment. The study showed that derailment risk is reduced by removing one or both of the anti-roll bars from the vehicle. Any deterioration in anti-roll bar stiffness is therefore highly unlikely to have contributed to the derailment.

Effect of vehicle speed

110 Network Rail implemented the TSR in order to reduce the amount of *cant deficiency* in an attempt to reduce the lateral curving forces on the track. At the normal permissible speed of 30 mph (48 km/h) and at the location where the derailment occurred, (radius measured on site 170 m, measured cant 47 mm), the cant deficiency was calculated to be 115 mm. Reducing the permissible speed to 20 mph (32 km/h) by means of a TSR was calculated to reduce the amount of cant deficiency to 25 mm.

111 However, reducing the cant deficiency results in a redistribution of lateral forces which, in turn, changes the attitude the wheelsets adopt relative to the curve. This change in attitude (increased angle of attack) results in an actual increase in gauge spreading forces. Gauge spreading forces act on both the high rail and the low rail.

112 The results of the parametric study confirmed that the likelihood of a derailment due to gauge spread increases at lower speed. This means that the TSR imposed did not actually reduce the likelihood of a derailment occurring, although a derailment at a lower speed was likely to give rise to reduced consequences.

Effect of rail-sleeper lateral stiffness

113 This part of the study investigated the effect of changing the rail-sleeper lateral stiffness. This stiffness reduces with deterioration of the track fastenings and a consequent reduction in the ability of the fastenings to resist outwards lateral movement of the rail caused by the lateral forces arising from the passage of rail vehicles.

114 When the lateral stiffness value used was double that used in the 'base case', a significant reduction in derailment risk occurred, due to reduced gauge spreading forces and a reduction in the amount of predicted gauge spread (see Appendix F).

115 Conversely, halving the lateral stiffness value used in the 'base case' significantly increased the gauge spreading forces and the predicted gauge spread.

116 The results demonstrated the importance of maintaining the track fastenings to prevent undue lateral movement of the rails.

Addition of a check rail

117 The study included two simulations to investigate the effect on derailment risk had a check rail been fitted. The first simulation was based on the check rail gap, based upon the standard check rail gauge of 1391 mm; whereas the second simulation was based on a much larger check rail gap that approached the maximum clearance at which the check rail would still contact the back of the wheel flange sufficient to remain effective.

118 The results of the study showed that a check rail would have reduced gauge spread and prevented the derailment occurring. The reason for this is that a check rail fitted to the low rail would have taken a proportion of the lateral reaction force normally carried by the wheel flange on the high rail.

Effect of wheel/rail friction

119 The degree of sidewear seen on the high rail was evidence that wheelsets had been running with their flanges in contact with the high rail. This behaviour is typical of operation on curves having radii as tight as those found on the Loop and results in the generation of a large lateral force at the tread of the wheel on the low rail which is reacted by the flange against the high rail. Reducing wheel/rail friction at the wheel tread will reduce the generated lateral force, thereby reducing the gauge spreading forces and hence the risk of derailment. This was clearly shown by the results of the study (see Appendix F).

120 However, in achieving friction levels low enough to significantly reduce derailment risk, for example by lubricating the wheel tread, an adverse effect on rail adhesion would result that would seriously affect traction and braking. Measures which reduce wheel/rail friction at the wheel tread are not therefore a practical measure.

121 The use of lubrication described in paragraph 120 above is different from the normal use of lubrication on the gauge face in order to reduce the amount of sidewear.

Effect of rail condition

122 Had new rails been present where the derailment occurred, the results of the study showed that they would have had no significant effect on the predicted gauge spreading and, therefore, no significant effect on the likelihood of the wheel on the low rail dropping into the four-foot. However, the likelihood of a wheel flange climbing on to the high rail then, subsequently, over the rail head is lower by comparison with the case where heavily *sideworn* rails are present.

123 New rails at the derailment site would not therefore have significantly reduced the likelihood of derailment, because there would have been no significant effect on the wheel on the low rail dropping into the four-foot. However, new rails could have mitigated the potential consequences of derailment by reducing the likelihood of flange climb of the high rail. It is also likely to be the case that fitting new rails would also include the fitment of new fastenings increasing the lateral stiffness and so further reducing the risk of derailment.

Comparison of vehicle type

124 A class 465 vehicle was modelled as being representative of a more modern type of train than the class 508 involved in the derailment at Liverpool. The class 465 is fitted with P3 motor bogies that are typical of the new generation of bogies developed since the BX1 bogies fitted to the class 507/8 trains. The most significant differences are that the bogies fitted to the class 465s are fitted with *yaw dampers* and, in the case of the motor bogies, the traction motors are mounted on the bogie frame rather than – in the case of the class 507/8s – being axle hung. Axle hung motors increase the unsprung mass and increase the forces on the track.

125 However, the study did not show any reduction in derailment risk – in fact the gauge spreading forces and gauge spread were both predicted to be higher for a class 465 that has bogies of a newer era as compared with a class 508.

126 This shows that neither the class 508 nor the class 465 is able to curve effectively on the tight radius curve fitted between Liverpool Lime Street and Central. It is possible, therefore, that effective curving could only be achieved by using rolling stock with specially designed radially steered bogies.

Identification of causal and contributory factors

Track and vehicle design

127 The study undertaken using the Vampire® programme identified that the derailment would not have occurred if a check rail had been fitted to the low rail. Such fitment was not a part of the design of the Liverpool Loop when first built. The normal criteria for such fitment is to curves of 200 m radius or less that are used by vehicles with a rigid wheelbase of 3 m or more. Although the Loop does not fully meet these criteria, it is considered that the absence of an installed check rail is a causal factor of the accident.

128 The study undertaken using Vampire® also showed that the class 508 trains are not able to curve effectively around the Liverpool Loop, resulting in high gauge spreading forces, and, therefore, a heavy maintenance workload for the track maintainer. It would also not be practicable to modify the suspension of these (or the very similar class 507 units) to improve matters, given that fitting primary trailing arm bushes of lower stiffness, while reducing gauge spreading forces, would adversely affect the vehicle ride on straight track. The study also showed that no improvement would be obtained by substituting a train having a suspension system as used on a typical more modern rolling stock design currently in service on the national network (see paragraph 107).

129 Furthermore, the report on the study carried out by AEAT in 2000 acknowledged that the class 507 and 508 units were designed for higher speed operation and their curving characteristics were not matched to the Merseyrail system, which contains a large proportion of curves that are less than 500 m radius.

130 The AEAT 2000 study included Vampire® simulations that investigated the effect of curve radius, tyre profile and curving speed on wheel and rail wear, and the report commented that all the evidence indicated a basic incompatibility between the vehicle and track design. The study concluded that excessive wheel flange wear and rail sidewear could be adequately controlled by well positioned and maintained flange lubricators, but any reduction in their effectiveness would quickly give rise to conditions of severe wheel and rail wear. This study recommended that the class 507 and 508 vehicles should be fitted with lubrication equipment, but this was not taken forward probably because trials with on-train lubricators had been carried out previously using a bitumastic lubricant. These trials were unsuccessful, because the equipment was unable to spray the lubricant in the quantities needed on tight curves at low speeds and, in any event, wheel and rail wear was being adequately controlled by flange lubricators.

131 At the time of the AEAT 2000 study, the high rail between Lime Street and Central was *mill heat treated rail*, and the report recommended its continued use. However, Network Rail staff stated that the mill heat treated rail was subsequently replaced by conventional rail to reduce wheel wear.

132 It is clear that the approach to maintaining the track in the Liverpool Loop must be properly based on a whole system approach taking into account the high lateral forces from the trains and their effect on the track and, more particularly, the rail fastening system. The evidence seen by the RAIB is that, although there have been previous studies carried out on vehicle-track interaction, the maintenance regime in place was not matched to the wear and deterioration caused by the trains.

133 Had a whole system approach been adopted, it is likely that maintenance practices would have been different. The absence of a systems approach to the maintenance of the track in the Liverpool Loop, by considering the interaction between the trains and the track, is a causal factor of the derailment.

<u>Track safety management system – organisation and staffing levels</u>

134 The maintenance of the track forming the Loop was the responsibility of Network Rail's Merseyrail track maintenance engineer (TME) within the Liverpool infrastructure maintenance manager's (IMM's) organisation. Under the TME were supervisors and staff whose responsibility it was to carry out the required inspections specified in RT/CE/S/103. The purpose of this was to ensure the line was fit for purpose or reported otherwise so that defects could be corrected and compliance with maintenance standards achieved, or steps taken to reduce unacceptable risk through operational restrictions such as a TSR.

135 The IMM also had an area track engineer (ATE) whose responsibilities included compliance with standards (including granting dispensations), carrying out audits and acting as the technical focus on track related issues in the Liverpool area. The ATE's functional head was the Territory track engineer, responsible for the renewal of the track asset and assurance of track standards, throughout Network Rail's London North Western Territory, whereas the IMM fulfilled the role of line manager. Similarly, the Merseyrail TME reported to the ATE on track technical matters but came under a Maintenance Delivery Unit Manager under the IMM for line management purposes. The IMM's organisation was responsible for ensuring that the track was maintained in a safe condition. The relevant part of the IMM's organisations is shown in Figure 13.

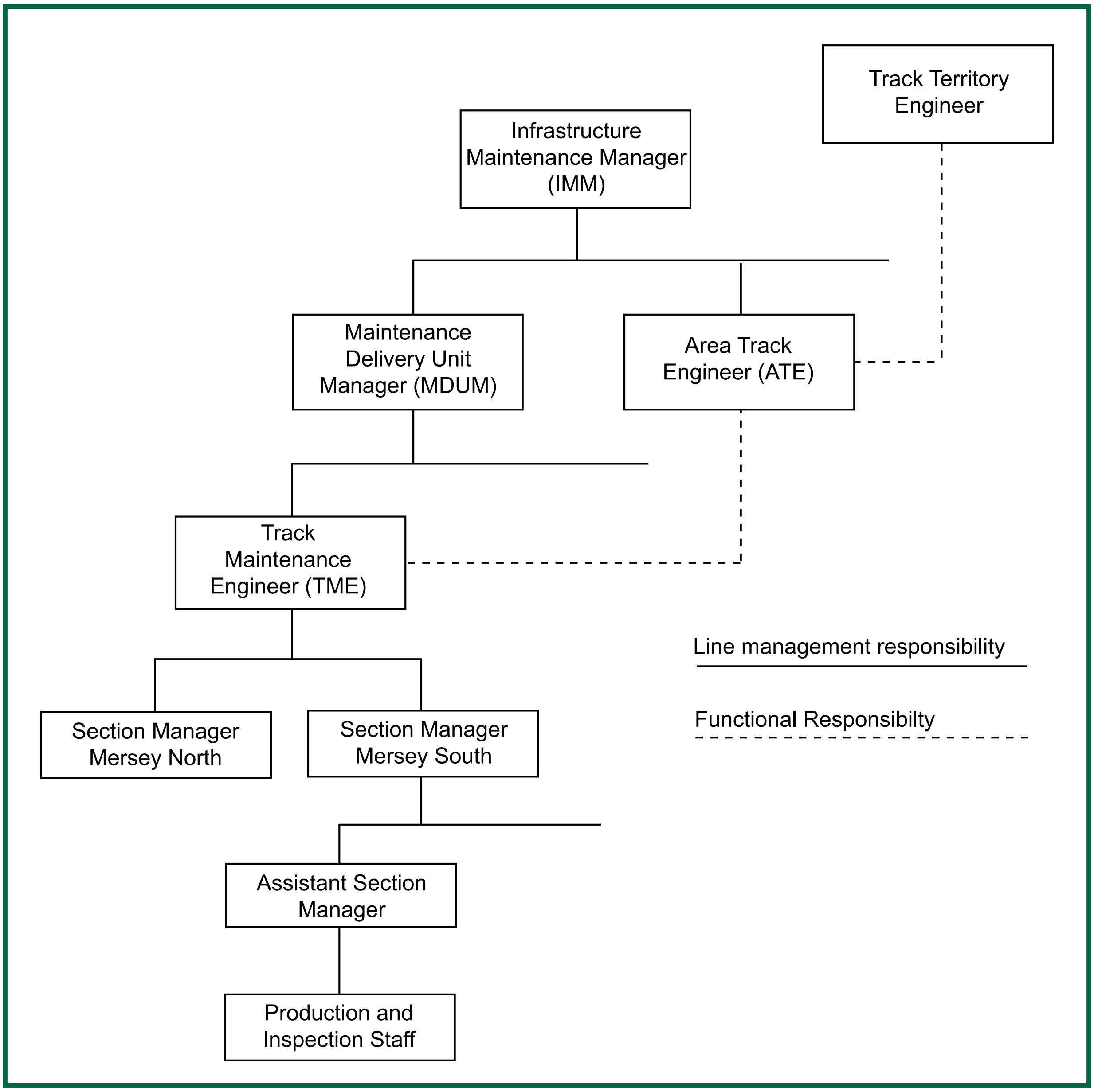


Figure 13: Chart showing part of the infrastructure maintenance manager's organisation

136 Auditing was carried out by the ATE as part of the method of assurance that track maintenance standards were being met. Mandatory subject areas were set by Network Rail's HQ, and these were supplemented by optional subject areas based on an examination of trends. The auditing system was aimed at an examination of management systems rather than asset condition.

137 The last audit carried out by the ATE on the Liverpool Area was carried out between 16 June 2005 and 26 July 2005. Although, including part of the Merseyrail TME's area, it did not include the Loop. The last audit carried out that included the Loop was in July 2003.

138 The Areas were required to submit a report on 23 track compliance indicators to the Territory Headquarters on a weekly basis. These were mainly inspection-related and included tie-bars in place for longer than the six months timescale permitted by RT/CE/S/103. The Territory's assurance engineer was required to visit the Areas every eight weeks to discuss the results of the track compliance indicators.

139 During the privatisation of British Rail, the infrastructure maintenance organisation covering the Liverpool area was set up as a discrete entity and sold to a contractor in 1996. In April 2004, the contractor surrendered the maintenance contract back to Network Rail, which then took over control of maintenance in the Liverpool area.

140 At the time of the accident, day-to-day maintenance of the Loop was under the control of the section manager (SM) Mersey South based at Liverpool Central. This SM covered the Loop, the Wirral lines and Sandhills to Hunt's Cross on the Link. Another SM (Mersey North) covered the remainder of the Merseyrail network. The SM Mersey South had one assistant.

141 The SM Mersey South and SM Mersey North shared a day inspection gang and a production gang (nine persons). In addition, both these SMs could call upon an additional six persons from a designated contract organisation. Further resources were also available from other contractors and from the former relaying gang at Tuebrook Sidings. The SM Mersey South had a night inspection gang that carried out the inspections on a section that included the Loop. This gang was originally intended to be made up of ten persons, but this had never been achieved and at the time of the derailment was made up of a track chargeman, two track patrollers and two lookouts.

142 Reductions in personnel took place just prior to the maintenance going to contract. Further reductions subsequently took place while the maintenance was under outside contract, when the philosophy of maintenance gangs covering defined portions of route was changed to one where all personnel within the area were considered to be a general resource able to be allocated to wherever the demand arose. Under this regime, it was the intention that resources would be brought in from elsewhere in the Liverpool and North Wales areas when needed for the Loop, but Network Rail's local staff stated that this had not worked out in practice.

143 The evidence seen by the RAIB during the course of its investigation indicated maintenance that was sub standard and, given the background of staffing issues, it is possible that the level of available personnel resources degraded the ability to carry out the maintenance that was required. This is therefore potentially a contributory factor, but further analysis would be necessary to be certain.

Track safety management system - inspections

144 At the time of the accident, the staff that carried out the basic visual inspections worked permanent nightshift under the supervision of a track chargeman, so contact with the section manager or his assistant working a normal dayshift was necessarily limited. However, the track chargeman did have regular contact with the section manager on a weekly basis – either by telephone or in person. There was little feedback however to the patrollers on what work was planned to be carried out as a result of defects booked. The night inspection gang also had no recourse to Network Rail's standards on track maintenance and, therefore, could not confirm maintenance requirements if they were unsure.

145 The system of track inspections as prescribed by RT/CE/S/103 was comprehensive and acted at several different levels with each level being certified by the one above. The system of track inspections could therefore be considered to be partly an audit process. The hierarchy of different inspections required by RT/CE/S/103 was as follows:

- Basic visual inspections carried out by track patrollers who had undertaken a track patrollers' course and had a certificate of competence. They were to observe and report any track defects needing immediate attention, and anything that had deteriorated significantly since the previous inspection. Patrollers were not equipped or required to carry out any measurements by the use of gauges, but were expected to take a minimal number of tools such as a spanner and a panpuller (to pull back into place any displaced Pandrol clips). Basic visual inspections of the Loop (track category 4) were required to be carried out weekly by RT/CE/S/103, although shortly before the derailment occurred, and arising from concerns over the condition of the track, Network Rail decided to increase the patrolling frequency to twice weekly.
- Visual track inspections carried out by supervisors included identifying work needing to be planned and carried out and reviewing trends in the condition of the track. These inspections included the measurement of track gauge and *cross-level* and for the Liverpool Loop Tunnel were required to be carried out every three months. The standard permitted one in two supervisor inspections to be carried out by another competent person approved by the TME.
- Visual track inspections carried out by the TME to review condition, trends, proposals for renewal and the quality of maintenance and renewal work. These were required to be carried out every 24 months for the track in the Liverpool Loop Tunnel.
- Visual inspections from the driving cab carried out by the supervisor and TME on a regular basis. In the case of the Liverpool Loop Tunnel, this was required every six months by the supervisor and every 12 months by the TME.
- In addition to the above, ATEs were required to carry out inspections to validate renewals' proposals, sample track inspections and cab riding. Territory track engineers were also required to inspect a sample of the renewals' proposals as part of a peer review process of the ATEs and carry out other sample track inspections, including by cab riding and inspection saloon. Other Territory and headquarters' engineers were also required to carry out sample track inspections.
- If, during any of the above inspections, the track was found to be unfit for traffic, an immediate speed restriction was to be applied or the line blocked to traffic.
- Separate inspections were also to be carried out of sidewear at sufficient frequency to detect when the limits on sidewear were close to being reached.

- Track geometry was also required to be measured at regular intervals by the track recording train. This included the measurement of gauge among other things and, in the case of the Liverpool Loop Tunnel, was required by the standard to be carried out every 12 months. In practice, Network Rail had decided to measure the track geometry more frequently than required at six monthly intervals in order to provide further information about the track; in particular, its behaviour under the passage of a train, including as a means to record dynamic gauge.

146 Work items identified through the inspection process were required to be prioritised and entered into the Minicom Information Management System (MIMS). This was then intended to be used for work planning purposes.

147 Prior to the accident, the previous six inspections carried out by track patrollers were as shown in Table 6.

Date of inspection	**Date signed by Supervisor**	**Signed by Section Manager (SM) or Assistant (ASM)**
24/10/2005	26/10/2005	SM
21/10/2005	26/10/2005	SM
12/10/2005	26/10/2005	SM
3/10/2005	7/10/2005	ASM
26/9/2005	29/9/2005	ASM
19/9/2005	26/9/2005	ASM

Table 6: Dates of last track inspections by patrollers before the derailment occurred

- Patroller's inspection reports were not always signed off by the section manager or his Assistant in the three days required by standard RT/CE/S/103. This situation prevailed over the course of many months – an example being the inspection carried out on 27 June 2005 not being signed off until 2 August 2005. Several inspections were signed off together on 26 October 2005, the day of the accident. The consequence of this was that, in some cases, inspections were being carried out and recorded by the patroller, but the work arising was not being booked into the system until much later (and with little or no feedback to patrollers in the 'Action Proposal' column of the report until much later, if at all), although it is acknowledged that many of the items were already known about from previous inspections and already entered into MIMS. More urgent items were also separately reported to the section manager by the track chargeman in charge of the patrollers.

- The Track Inspection Handbook containing guidance to staff doing track inspections on ensuring compliance with Standard RT/CE/S/103 required reports of defects submitted by patrollers to be allocated a priority code based on the urgency with which they should be rectified. Priority codes were to be allocated either by the patroller or the supervisor, In the case of the Loop, it was left to the supervisor to allocate the priority codes (or to reprioritise those allocated inappropriately in the few cases where the patroller had allocated priority codes directly). An example of a priority code is the number of ineffective sleepers in any 60 foot section of track unable to hold gauge. For the track in the Loop, four such sleepers in a 60 foot section would be coded M1, meaning that work to correct the defect should be carried out within a month subject to any reassessment or reprioritisation arising from subsequent inspections carried out.
- Defects allocated with priority codes were entered into MIMS with the objective of using the resulting workbank to plan the work to be carried out. However, local Network Rail staff stated that there were so many defects booked into MIMS that it was no longer a viable system for planning work. Instead, the section manager used his own experience and knowledge of what was in MIMS to plan the work to be carried out.
- The inspection reports on inspections carried out just before the derailment occurred recorded very few defects. The inspection on 24 October 2005 only recorded the following items between Lime Street and Central:
  - *gauge corner cracking*;
  - sideworn rails;
  - five broken tie-bars.

  This was not an accurate record of the extent or location of track deterioration in the tunnel;
- It was also apparent that defects had been recorded at one visual inspection and then not recorded at the following one even though there would have been no opportunity for the work to have been planned and executed in the intervening time. An example is the recording of dirt around the housings during the inspection on 12 October 2005, but not recorded on the following inspection on 21 October 2005. The section manager did not sign either of these records off until 26 October 2005.

148 The supervisor's inspections had given rise to more detailed reports, but are characterised by defects carried forward from one inspection to another. For example, 'renew nylons to help improve gauge (1455 mm)' was booked as a defect at 1 mile 440 yards at the inspection on 4 November 2004 and given an M3 priority code. Exactly the same defect was booked at following inspections through to the inspection on 17 August 2005 and, again, given an M3 priority code. This same defect was not booked at an additional inspection carried out on 16 September 2005 (by a track chargeman who was deemed to be competent) following the cancellation of planned work, but it has not been established whether remedial work had been carried out in the interim, or whether the inspector knew that the defect had already been entered into the MIMS workbank.

149 It is apparent from Table 7 that the section manager had not met the requirement in RT/CE/S/103 to carry out a minimum of one in two of the inspections on an alternate basis and so maintain a good overview of the condition of the track. The dates of inspections carried out by supervisors are in Table 7.

Date of inspection	Whether by SM or ASM
16/9/2005	Track Chargeman
17/8/2005	SM
24/5/2005	ASM
5/2/2005	ASM
9/11/2004	SM

Table 7: Dates of last supervisors' inspections before the derailment occurred

150 The TME's last inspection before the derailment was on 19 August 2004. The report arising from this required tie-bars to be fitted at two locations between Lime Street and Central within a month. There were no corresponding entries in the tie-bar register to confirm that they were in fact fitted.

151 Inspections from the driving cab had not been carried out at the required frequency, because other inspections had taken priority – the most recent by a supervisor having been on 26 January 2005.

152 The last run of the track recording train prior to the accident had been on 16 February 2005. An additional run, planned for August 2005, did not take place because of works being undertaken to renew the track elsewhere on the Merseyrail network at Hamilton Square. The 16 February 2005 run recorded five instances where the dynamic gauge exceeded 1465 mm, requiring manual inspection within 36 hours and other action to control gauge as required by standard RT/CE/S/103. This was achieved by fitting tie-bars which, as explained in paragraph 68, should only be used as a temporary measure and for no more than six months.

153 The foregoing indicates that the track inspection system, crucial to the correct identification and monitoring of defects so that they could then be planned for remedial action was not as robust as it should have been.

154 The training of staff carrying out inspections (such as is covered by the patrollers' training course) is general to track anywhere on the network and is not specific to the special features that exist in the Liverpool Loop. The patroller's certificate of competence correspondingly is general to the network. Given the special features of the Loop (drainage, fastenings, curve radius, cant, level of contamination etc.), it is appropriate that specific competences are considered

155 It is considered that the weaknesses in the track inspection system were a causal factor of the accident.

Renewal of the track between Lime Street and Central

156 The renewal of the track between Lime Street and Central was not programmed by Network Rail until the organisational changes occurred creating the London North Western Territory. This also occurred shortly after Network Rail took over the maintenance of the Loop from an outside contractor. The local Liverpool Area staff never made a formal renewal proposal, even though they recognised that the track between Lime Street and Central was at the stage of its life cycle where it was difficult to maintain and required renewal.

157 The maintainer (both when a contractor, and since) did take action to try and keep the track in a serviceable condition pending its renewal through the normal process of re railing and by the use of the Pandrol e-Plus clips. However, not enough attention was given to ensure that the track was maintained in a safe condition – for example, e-Plus clips were not fitted where the derailment occurred.

158 The failure to maintain the track adequately in the area where the derailment occurred pending its complete renewal was one of the causal factors of the accident. Earlier renewal would have reduced the maintenance workload and prevented the accident occurring.

The adequacy of the rail fastening system

159 The rail fastening system of housings, insulators and clips was not able to maintain the gauge to acceptable limits leading to the widespread use of tie-bars. Work had been carried out in the past to renew housings (including at the location where the derailment occurred) and to fit intermediate baseplates, but some of this work was not as effective as it might have been – Network Rail staff advised that trains had been allowed to run on track where new housings had been fitted before the surrounding grout had fully set causing the new housings to be loose and to move out of their set position.

160 A recent initiative was to fit Pandrol e-Plus clips and gauge management insulators able to deliver a higher toe load onto the rail foot. As a short term measure pending renewal, the use of e-Plus clips was effective, but they had not been fitted in the area where the derailment occurred.

161 The aggressive environment of the tunnel exacerbated problems of corrosion of both the rail foot and the adjacent housings allowing the rail to shuffle during the passage of trains causing pushing out of the nylon insulators and clips to break. There was significant evidence on site of the rail shuffling during the passage of trains. Loss of rail foot was not specifically measured, as it was sidewear that drove rail renewal, but rail with a good width and depth of foot was necessary to prevent gauge being compromised.

162 The failure of the rail retention system to prevent the gauge widening to unacceptable limits was one of the causal factors of this accident.

The use of tie-bars

163 The fitment of tie-bars had to be recorded in a register, but it was accepted by local staff that this was not an accurate reflection of the true picture on the use of tie-bars. The first entries in the register obtained from Network Rail of tie-bars fitted between Lime Street and Central were dated 1 August 2003 (see paragraph 70).

164 Before this, HMRI carried out an inspection of the 'management of safe track conditions in Network Rail's North West Zone' between January and March 2003. This identified the existence of 159 tie-bars throughout the Zone that had been in place for longer than six months. Three of these were between Lime Street and Central stations and had been fitted on 15 January 2002. HMRI subsequently issued an Improvement Notice dated 26 March 2003 requiring permanent repairs to be carried out so that the 159 tie-bars could be removed. The compliance date was 25 July 2003, and this was achieved.

165 Tie-bars had therefore been fitted to the Loop over a period of several years, and left on for far longer than six months, contrary to the Network Rail standard and good practice (see paragraph 66). Dispensations had been granted verbally on the six month time limit by the area track engineer on the understanding that they would remain in place until the track was eventually renewed. However, following the derailment, it was found that five of the fitted tie-bars in the vicinity of the derailment were broken and many others were loose (although it is accepted that these may have been tie-bars that had been loosened off following the completion of remedial work – see paragraph 73).

166 When gauge spread occurs, the track spreads by both lateral movement and by the rails rolling outwards. The combination of these two factors where lateral resistance is low can give rise to large relative movements of the rail heads when subjected to a gauge spreading force by a train. Tie-bars are only fitted around the rail foot and will only impede lateral movement and not the tendency of rails to roll outwards under the passage of a train if there is insufficient toe load provided by the Pandrol clips to prevent this.

167 The fatigue life of the tie-bars fitted in the Loop Tunnel was not known and was evidently exceeded in the case of those that broke. This was exacerbated by the practice of fitting previously used tie-bars that were already part way through their fatigue life. The fatigue life will be dependent on the circumstances under which tie-bars are fitted. The forces on them will be greater where fitted to a 210 m radius curve with dry rail as was the case on the Liverpool Loop as opposed to fitment on straight track.

168 The number of tie-bars in place for more than 6 months was one of the 23 items that had to be reported weekly to the Territory. The Territory was therefore aware that tie-bars were in place for greater than six months and also aware that they were considered by the Liverpool Area to be necessary pending the renewal planned for early 2006/7.

169 The over-reliance and lack of proper control on the use of tie-bars was a causal factor of the accident. They did not allow for any proper assessment of the factor of safety remaining in the track and were a too readily available method of holding the gauge when it would have been better to carry out more permanent repairs.

Keeping the track clean

170 Much of the rail foot, housings and fastenings were found on site to be heavily contaminated with a substance thought to consist of human hair, skin, brake dust and other deposits all congealed together by the wet environment.

171 The contamination present was said by all concerned to be corrosive, and indeed corrosion of the rail foot, housings and fastenings was evident to the RAIB inspectors on site. To investigate this further, a sample of the deposits was submitted to the Health and Safety Executive's Health and Safety Laboratory (HSL).

172 The HSL carried out a chemical analysis of the deposits and found that they contained chlorides and sulphates possibly originating from coastal air, ground water or road water. They confirmed that, when wet, the deposits would corrode steel rail and track fastenings.

173 The HSL also assessed the likely rate of corrosion and considered that general loss of thickness of the rails and fastenings would be between 0.05 mm/year and 0.15 mm/year but, where corrosion pitting had occurred, the local depth of attack could exceed the long-term rates by up to three times.

174 Jet washing of the track had been carried out at various times in the past to remove the build up of corrosive substances, but this had not been done since July 2004 because of shortage of resources.

175 Keeping the track clean would appear to be a key process necessary to prolong the life of track components, improve the track environment and facilitate maintenance. The lack of any robust process to keep the track clean is considered to be a contributory factor of the accident.

Severity of consequences

176 A 20 mph (32 km/h) temporary speed restriction had been imposed which, although possibly increasing the likelihood of a derailment occurring, did serve to mitigate the consequences of any derailment. Furthermore, the train that derailed was already slowing for the stop at Liverpool Central, so the derailment occurred at a speed of only 12 mph (19 km/h). This resulted in limited consequences arising from the derailment.

Response of others

177 The welfare of the passengers following the derailment was well taken care of, and the evacuation of the train was carried out in an orderly and systematic manner. Had the tunnel lighting not been available, the fact that the train emergency lighting expired as soon as it did may have been more serious.

178 The removal of metal plates used to cover the drainage channel (paragraph 74) to enable tie-bars to be fitted, presented a risk to passengers being evacuated that could have been severe if the circumstances of the evacuation had been more urgent or the lighting had failed. The new track infrastructure installed since the accident (paragraph 198) has eliminated this risk between Liverpool Lime Street and Central.

179 In order to improve the performance of the emergency lighting system, Merseyrail is proposing to change the type of battery fitted to the class 507 and 508 units following the completion of successful trials.

180 Railway Group Standard GM/RT2176 requires that for new trains on the main line network, emergency lighting levels should be available for at least 90 minutes after the failure of the main lighting system. The Liverpool Loop tunnel is perhaps more akin to London Underground where the duration of the emergency lighting should be a minimum of two hours. London Underground tunnels are also provided with separate emergency lighting (Recommendation 8).

Summary of the accident

181 A diagram showing the immediate cause, causal factors and contributory factors is summarised in Figure 14.

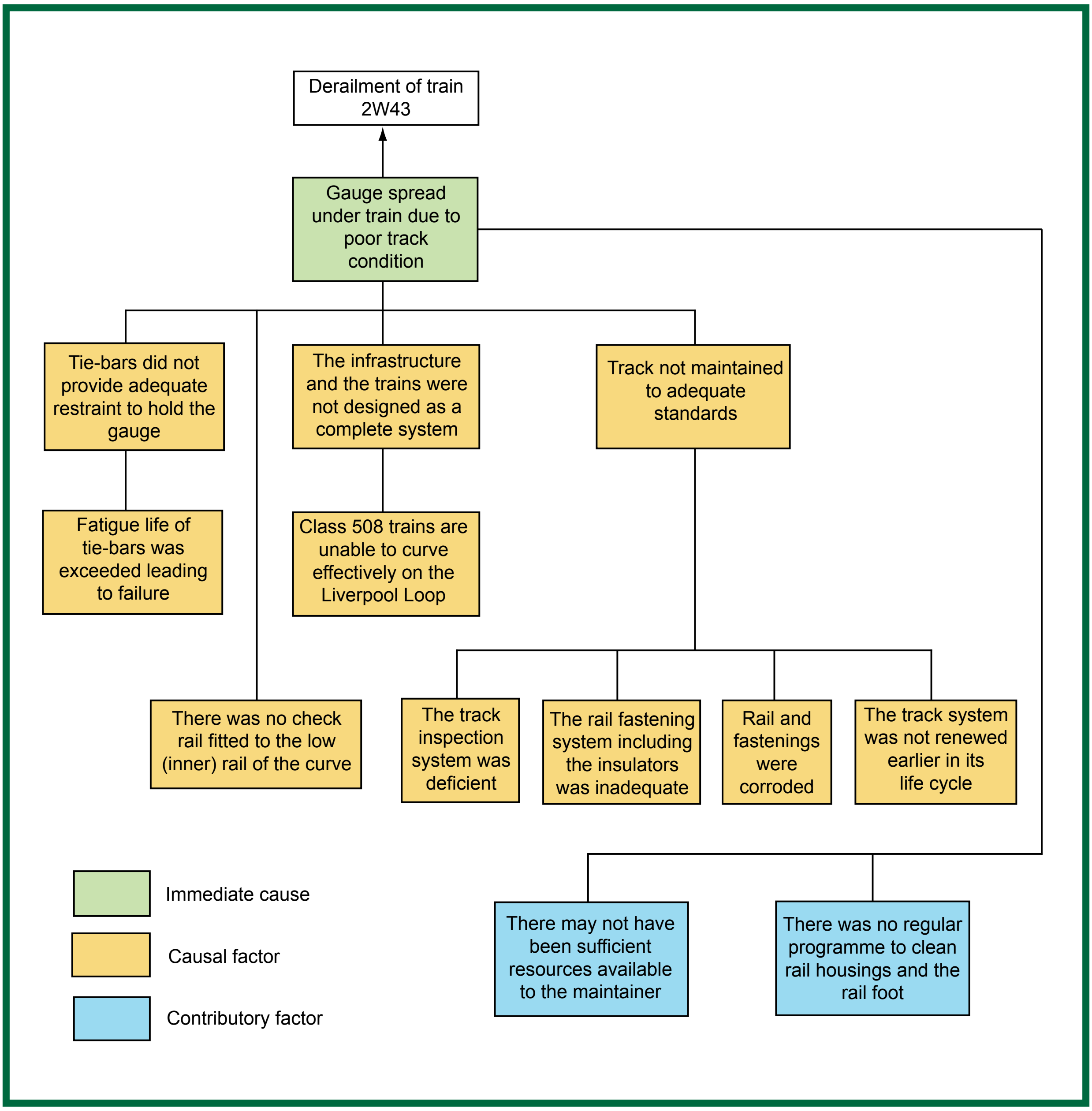


Figure 14: Causal analysis diagram

Conclusions

Immediate cause

182 The derailment occurred on a section of plain line subject to a TSR of 20 mph (32 km/h). The immediate cause was the spreading of the track gauge during the passage of train 2W43 to such an extent that the right hand leading wheel of the last bogie was able to drop down the gauge face of the rail. This started the subsequent derailment of all the wheels on that (trailing) bogie before the train finally came to a halt.

183 The gauge spread at the POD by two mechanisms – a sideways movement of the rails ('shuffle') followed by an outwards rotation of the rails.

184 The dynamic gauge spreading described above was caused by the poor condition of the track.

Causal and contributory factors

185 The causal analysis diagram at Figure 14 showing the causal and contributory factors that led to the derailment has already been referred to.

186 Neither the handling of the train nor the signalling system contributed to the derailment.

187 The causal factors of the accident break down into three main areas:

- the design of the infrastructure and the trains which were not considered as a complete system;
- the maintenance of the track that did not keep up with the deterioration that occurred;
- the use of tie-bars to hold the track gauge.

188 The degree of incompatibility between the class 508 (and class 507) trains using the Loop and the infrastructure provided a significant challenge to the maintainer. The nature of the infrastructure design containing a sharp radius curve without a check rail and the suspension characteristics of the trains using it gave rise to high lateral forces on the track. This, in turn, caused severe difficulties for the track maintainer both in the degree of sidewear occurring and in maintaining the rail fastening system to prevent gauge spread. Added to this was a very aggressive environment causing corrosion of the rail foot, the housings and the clips.

189 There was little evidence that a systems approach had been adopted to determine an appropriate maintenance regime, other than a consideration of wheel and rail wear. The maintenance of track needs to take into account the characteristics of the trains running over it necessitating an assessment of the risks arising from the train and infrastructure interface. The outcome of such an assessment should be an appropriate maintenance system and regime that may be required to go beyond the established track and rolling stock maintenance standards (Recommendation 1).

190 The training of personnel who inspect the track is generic to the network and does not include the unique features in the track system in the Liverpool Loop such as the track fastening system, the tight radius curves, the degree of cant, the amount of sidewear the system of drainage and the accumulation of contamination around the fastenings and rail foot. The appropriate maintenance regime described in paragraph 189 above should therefore include a competence assurance system that ensures that maintenance staff are competent to maintain the Liverpool Loop (Recommendation 2).

191 The RAIB's investigation identified weaknesses in the track inspection regime and the corrective actions applied. These should be dealt with by management action by Network Rail to ensure that the system of track inspection was as a minimum in full conformance with standard NR/SP/TRK/001 pending any enhanced measures that may arise from the risk assessment described in paragraph 189.

192 The main deficiency in the area of corrective actions was the widespread use of tie-bars of unknown provenance and fatigue life to hold the gauge rather than carrying out more durable repairs such as greater renewal of housings, more fitments of intermediate baseplates or even completion of the fitment of Pandrol e-Plus clips throughout. The use of tie-bars needs to be under tighter control to ensure that they are not used in quantity as a long term measure to control gauge. The process for granting dispensations on the 6 months time limit for using them needs to be more robust, and work is required to investigate their fatigue life in different applications so that, when fitted to the track, they are not likely to break due to fatigue (Recommendations 3, 4 and 5).

193 It is self-evident that complete renewal of the track (as has now been carried out) at an earlier stage would also have prevented the derailment. A check rail would also have prevented the derailment.

194 Following the risk assessment described in paragraph 186, it is incumbent upon each party to ensure that sufficient competent resources are provided to ensure that the required maintenance can be carried out. It is possible that, at the time of the derailment, staffing levels provided by Network Rail did not correctly match the workload owing to changes that occurred over previous years (see paragraphs 134 - 143). This is not considered to be a matter that was directly causal of the accident, but it probably made it more likely to occur (Recommendation 6).

195 Finally, the aggressive environment had not been properly mitigated by the use of a planned system of jet-washing for some years, although it had been carried out on an ad-hoc basis. Such a system would appear to be essential in reducing corrosion and, therefore, extending the life of the asset and making derailments less likely to occur. Again, this is not considered to be directly causal of the accident, but it did make it more likely to occur (Recommendation 7).

Measures that have already been taken

196 When the cause of the derailment became apparent, the RAIB issued an Urgent Safety Advice on 27 October 2005 to railway operators emphasising the requirement to maintain track of the form installed in the Liverpool Loop Tunnel to gauge (see Appendix G).

197 Following the derailment, Network Rail fitted more intermediate baseplates and more e-Plus clips before resuming operations. This ensured that the track would be safe for trains to run on until its planned renewal.

198 Network Rail renewed the complete track infrastructure between Liverpool Lime Street and Central during a six week blockade of the line that started on 14 April 2006. This did not include the fitment of a check rail.

199 Merseyrail had already progressed the fitting of improved batteries to the class 507/8 fleet before the accident. These had been static tested and fitted to one train as a trial. The results were very encouraging and indicated that the duration of the emergency lighting could be as much as three hours.

Recommendations

200 The RAIB's recommendations are directed at those parties who the RAIB believes are best placed to mitigate the identified risks (the implementers). When these parties have considered the recommendations they should establish their own priority and timescale for the necessary work, taking in to account their health and safety responsibilities and the safety risk profile and safety priorities within their organisations.[1]

1 For the Liverpool Loop, Network Rail supported by Merseyrail should carry out a risk assessment of the compatibility between the rolling stock and the infrastructure and create an appropriate maintenance regime that may require going beyond current maintenance standards applicable to the track and to the trains. The risk assessment should consider parameters relating to track and trains, the operation of trains and the environment such as speed including TSRs, curvature and stiffness. It should also consider how these elements interact at the wheel-rail interface. Network Rail should also extend this study to see if the effect of lowered speed restrictions increasing gauge spreading forces could exist elsewhere on their system.

2 Network Rail should review and change the competence assurance system covering the staff that maintain the track in the Liverpool Loop tunnel to ensure that it is appropriate to the special features of its construction.

3 Network Rail should review and enhance, where appropriate, its current instructions on the use of tie-bars in order to clarify under what circumstances their use is appropriate and to prevent situations (as occurred on the Loop) where an over-reliance on their use may occur at the expense of carrying out more permanent repairs.

4 Network Rail should require that any dispensations on the six months timescale applying to the use of tie-bars should be justified by risk assessment and formally authorised at Territory level.

Continued

[1] The RAIB addresses its recommendations to ORR(HMRI), the Safety Authority, in accordance with Article 25(2) of the European Railway Safety Directive 2004 (the Directive) and Regulation 12(2)(a) and (b) of the Railway (Accident Investigation and Reporting) Regulations 2005 (RAIR). The RAIB does this to enable ORR(HMRI) to discharge its responsibilities under Article 25(2) of the Directive and Regulation 12(2)(a) of the Regulations, namely that they must ensure that all RAIB recommendations addressed to it are duly taken in to consideration and where appropriate acted upon by the end implementer.

The end implementer is required under Regulation 12(4)(b) of the Regulations, to provide the Safety Authority with the full details of the measures/actions they intend to take to implement the recommendation and the timescales for securing that recommendation. The timeliness of this response to the Safety Authority is dictated by the Safety Authority's duty under RAIR Reg 12(2)(b) to report to the RAIB, without undue delay or within such other period as may be agreed with the Chief Inspector.

5 Network Rail should carry out studies to predict the fatigue life of tie-bars in different applications and ensure consistency with standards and practice to deliver tie-bars that are fit-for-purpose for all situations.

6 Taking the outcome of the work in Recommendation 1 above, Network Rail should review the level of resources - both staff and supervision - available to the Merseyrail Track Maintenance Engineer and ensure enough are provided to implement and then sustain the appropriate maintenance regime required for the Liverpool Loop.

7 Network Rail should implement a system to regularly clean the track bed of the Liverpool Loop Tunnel so that the build up of corrosive contaminants is minimised.

8 Merseyrail should implement improvements to the emergency lighting system fitted to the class 507 and 508 trains to increase the duration for which it is effective in an emergency.

Appendices

Glossary of abbreviations and acronyms — Appendix A

AEAT	AEA Technology Rail
ATE	Area Track Engineer
BDMSO	Battery Driving Motor Standard Open
BREL	British Rail Engineering Limited
BTP	British Transport Police
CCTV	Closed circuit television
DMSO	Driving Motor Standard Open
EMGTPA	Equivalent Million Gross Tonnes per annum
HMRI	Her Majesty's Railway Inspectorate
HSL	Health and Safety Laboratory
IECC	Integrated Electronic Control Centre
IMM	Infrastructure Maintenance Manager
MIMS	Minicom Information Management System
POD	Point of derailment
SM	Section Manager
SSI	Solid State Interlocking
TME	Track Maintenance Engineer
TSO	Trailer Standard Open
TSR	Temporary Speed Restriction

Glossary of terms **Appendix B**

Angle of attack	The angle between a wheelset axle and the curve radius representing the angle of the wheelset as it attempts to traverse the curve.
Anti-roll bar bush	A component in the suspension of a railway vehicle that is part of an anti-roll bar that controls the amount of roll of the vehicle body relative to the bogies.
Axle counters	Track mounted equipment which counts the number of axles entering and leaving a track section at each extremity. A calculation is performed to determine whether the track is occupied or clear.
Baseplates	Metal casting which supports and holds a flat bottomed rail on a sleeper.
Cab secure radio	A radio system allowing direct and one-to-one communication between a signaller and a train driver.
Cant	The amount by which the high rail on a curve is raised above the low rail.
Cant deficiency	Represents the amount of lateral acceleration seen by the train in the plane of the track during curving. It is generally recorded as the difference between actual cant of the track and the cant that would be required to give zero lateral acceleration in the track plane.
Cant gradient	The rate of change of cant with specific distance along a railway track.
Check rail	A rail provided alongside a running rail inside gauge to give guidance to wheelsets by restricting the lateral movement of the wheels.
Conductor rail	A rail mounted on insulators standing outside the normal running rails thorough which DC electricity is supplied to electric trains on the third rail system.
Cross-level	The difference in level between the two running rails of a straight track.
Dynamic gauge	The gauge that exists under the passage of a train.
e-Plus clips	A type of Pandrol clip for use where additional toe load on the rail foot is required.
Electric multiple unit	An electric train comprising two or more cars that can be driven and controlled from the leading driving cab as a unit.
Engineer's Line Reference	A method of designating stretches of railway on the main line railway network.
Facing points	Points where two routes diverge in the direction of travel.
Fatigue life	The period of time before the failure of a component occurs that is caused by stresses that have been repeated many times.
Field side	The direction away from the four-foot side.

Flange lubricator	A device for discharging lubricant along the gauge face of a rail operated by the wheels of a train.
Four-foot	The area between the two running rails of any one railway track.
Gauge corner	The curved portion of the rail head between the running surface of the rail and the gauge face.
Gauge corner cracking	Successive fatigue cracks on the corner of the rail between the gauge face and the rail head caused by the interaction between rail vehicles and the track.
Gauge face	The inner running face of a rail.
Gauge management insulator	A type of insulator for use with Pandrol e-Plus clips.
Gauge spread	Lateral outwards movement of the running rails.
Gauge spreading force	Force imparted by the wheels of a railway vehicle that acts to try and displace outwards the running rails laterally.
Gauge spreading tests	Tests carried out to determine the lateral displacement of the rails for a given force applied to the web of each rail.
Gearcase	The casing that encloses the drive between a motor and a wheelset.
Headwall	The flat wall where the tunnel section enclosing a station platform reduces to the narrower diameter running tunnel between stations.
High rail	The outer rail of a curved portion of track.
Housings	Fitted to sleepers and into which Pandrol clips are fitted.
Hunting	Unstable sideways movement of a wheelset as it moves along the track.
Integrated Electronic Control Centre	A power signal box where all data displays, interlockings etc. are computer controlled and under normal circumstances routes are set automatically.
Insulator	A nylon insert that fits between a housing and the rail foot.
Lateral stiffness	The resistance to lateral displacement of the rails on their baseplates.
Low rail	The inner rail of a curved portion of track.
Mill heat treated rail	Rail that has been specially heat treated during manufacture to increase its resistance to wear.
Pandrol clips	A proprietary type of track fastener that secures rail to sleepers.
Parametric study	A study carried out where various factors are changed to see what effect there is on the final outcome.
Point of derailment	In a derailment, the precise point where the first wheel derailed. The sleeper closest to this on site is normally designated as sleeper zero.

Primary suspension	The suspension system that acts between the wheels and the bogie.
Primary trailing arm	A suspension component that controls the amount of lateral stiffness of bush the *primary suspension*.
Secondary air suspension	A component of the secondary suspension that acts between the bogies and the body of a vehicle.
Short circuiting bar	A tool that can be used to short circuit the electric current in a conductor rail and cause the current to be switched off.
Sidewear	The reduction in railhead width due to wear caused by *flange contact* with the rails as trains run round a curved track.
Sideworn	The existence of sidewear.
Solid State Interlocking	Interlocking of points and signals through a computer in the signal box. Prevents the accidental setting of conflicting routes.
Static gauge	The gauge measured with no train present.
Stray current	Electrical current between the train and its intended return path through the running rails to the substation that escapes into the surrounding earth.
Switch rail	The moving portion of rail on each side of a set of points.
Temporary speed restriction	A temporary reduction in the permissible speed along a section of railway line.
Tie-bar	A temporary piece of equipment that can be fitted across the bottom of two rails to prevent gauge widening occurring that is no part of the design.
Toe insulator	An insulating ferrule fitted to the end of a Pandrol clip that bears on the rail foot.
Toe load	The load exerted on the rail foot by a rail fastening such as a Pandrol clip.
Torsional stiffness	A railway vehicle's ability to withstand angular deflection when twisted along its length.
Track category 4	The track category based on train speed in the range 61 mph (98 km/h) to 76 mph (122 km/h) and Equivalent Million Gross Tonnes per annum in the range 6 to 15.
Track gauge	The specified distance between the rails of a railway track, usually 1435 mm.
Track recording train	A train made up of special vehicles for recording the geometry of the track.
Track twist	A type of track irregularity.
Trainstop	A device fitted to the track that will operate a tripcock on a vehicle when an associated signal is at danger.

Tread corner	The transition between the tread surface of a wheel and its vertical face.
Tripcock	A device fitted to a train that when operated by a trainstop will cause the brakes to be applied.
Two-aspect colour light (signal)	A signal that can only show two normal states.
Vampire®	A proprietary software package that can simulate the interaction between railway vehicles and the track and a registered trademark of AEA Technology Rail.
Wheelset back-to-back dimensions	The spacing apart of the two wheels on an axle.
Witness mark	A physical mark such as made on a rail by a derailed wheel.
Yaw damper	That part of the suspension system controlling rotation of a bogie around a vertical axis.

Site location diagram

Appendix C

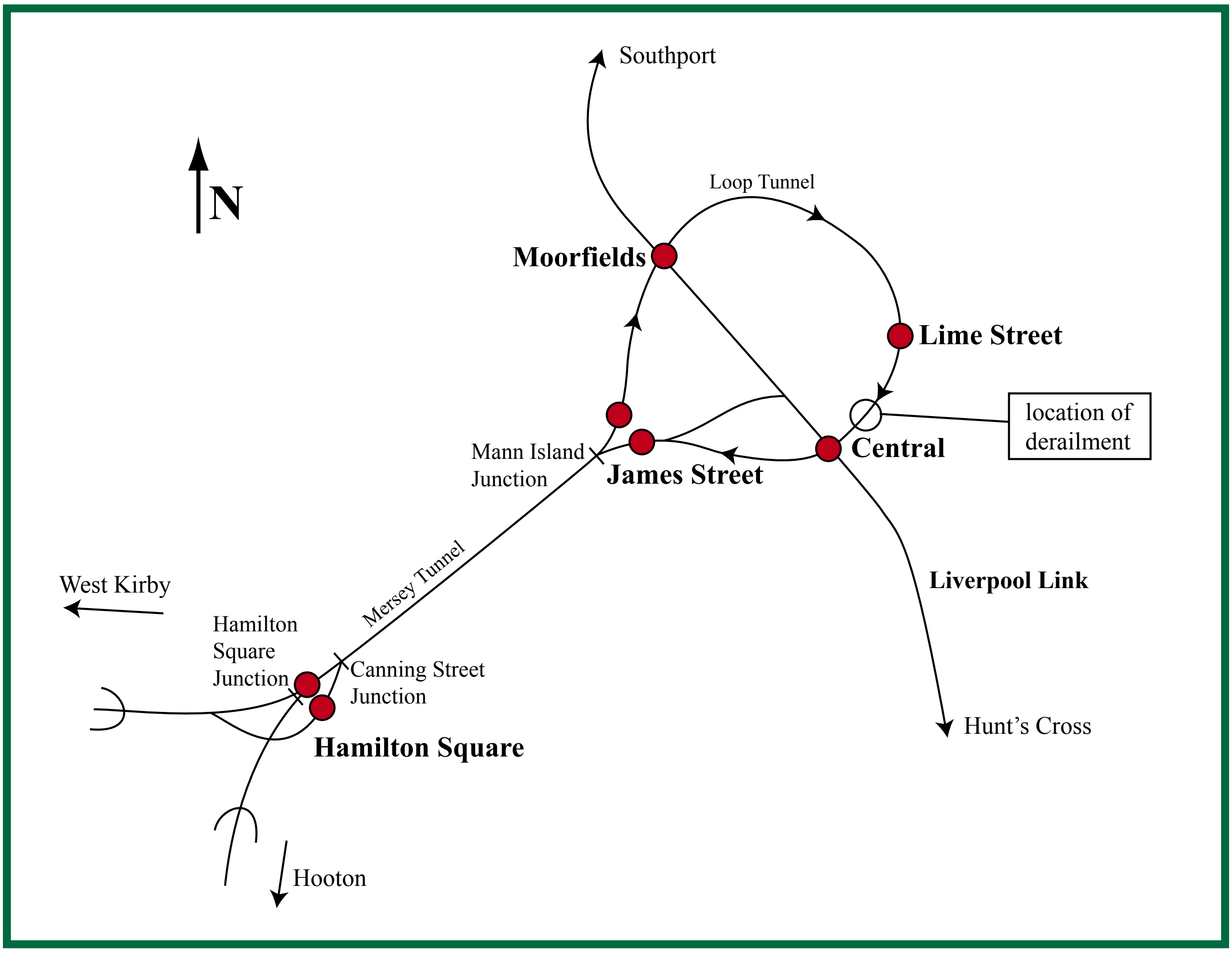
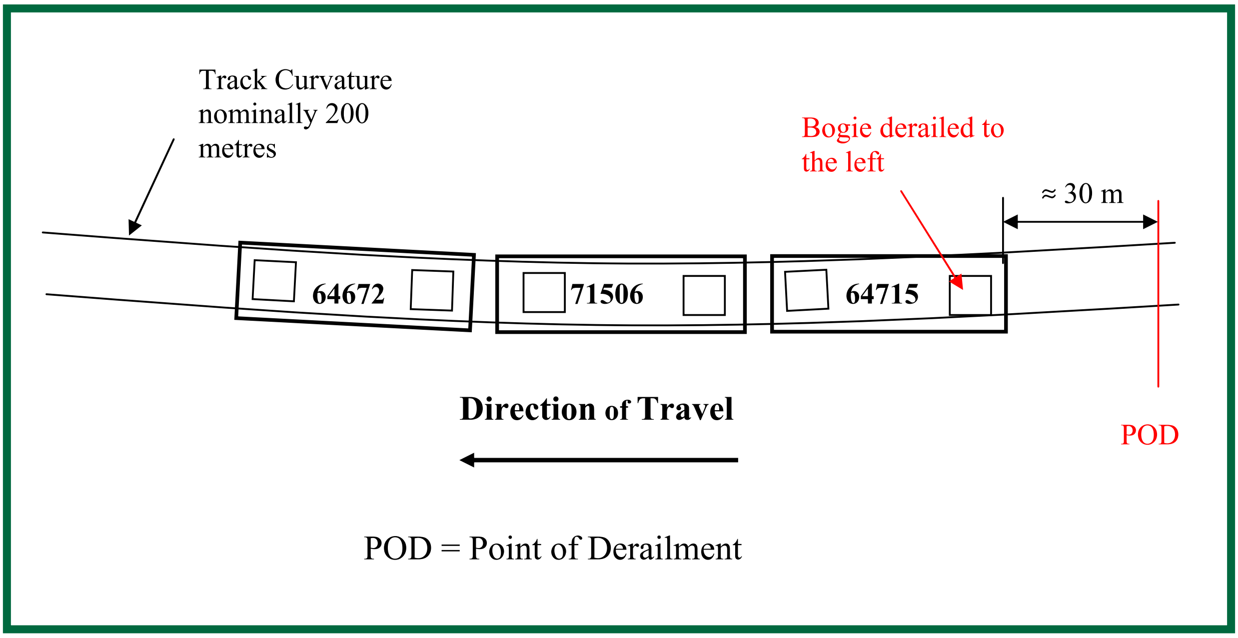
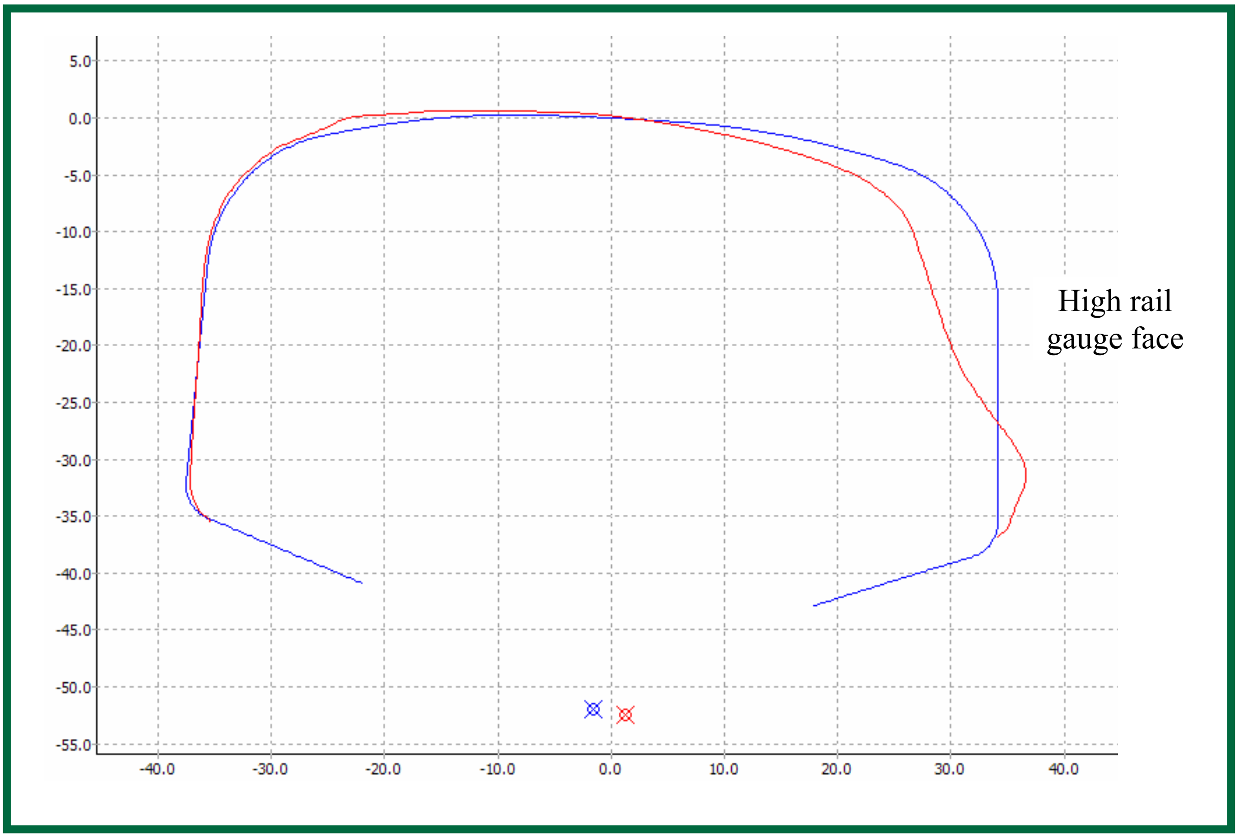


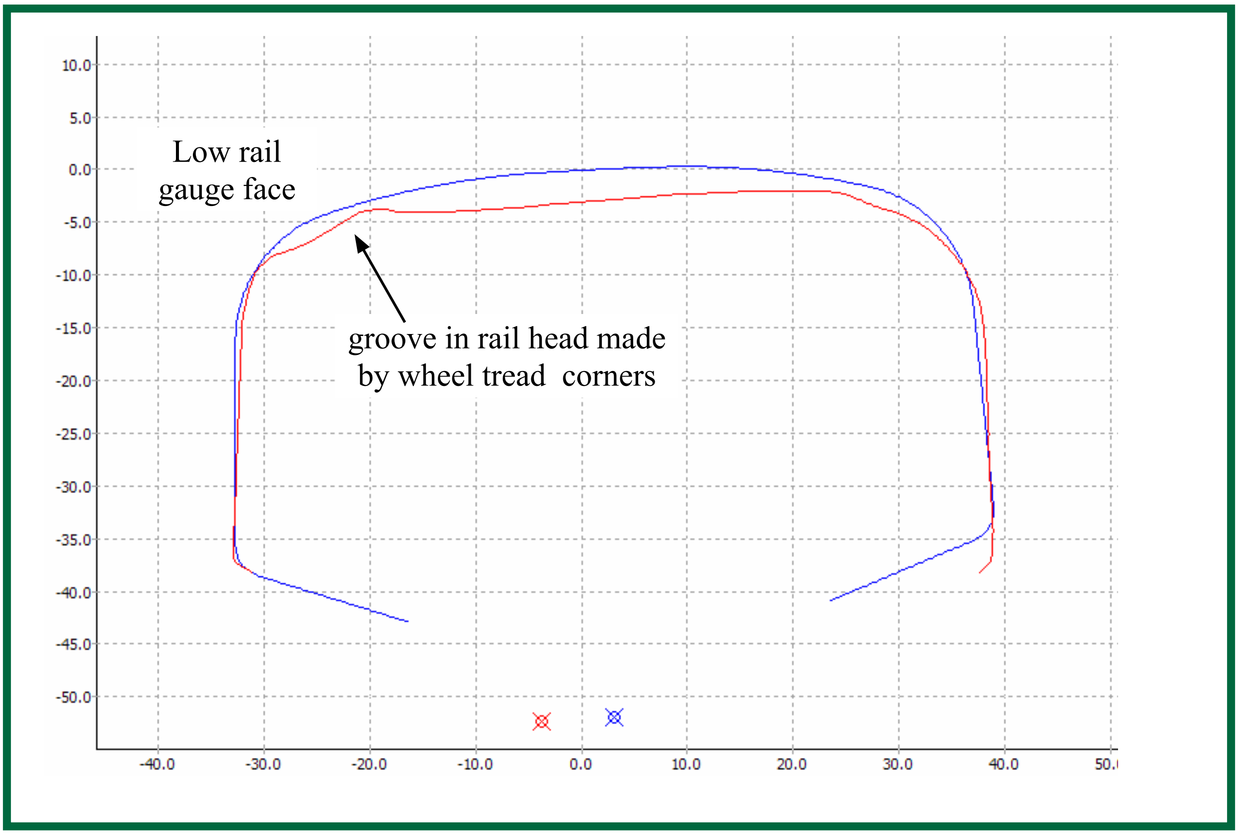
Diagram showing final position of rolling stock **Appendix D**



Left and right hand profiles at the POD

Note: the red outlines are the rail profiles as measured at the derailment site





Summary of parametric study results

Factor	Case	Gauge spreading force (kN) (at wheelset 3) Sleeper 0	Max	Change In max value relative to base case (kN)	Gauge spread (mm) (at wheelset 3) Sleeper 0	Max	Change in max value relative to base case (mm)
Base case (class 508)	No Change (20 mph)	17.7	26.0	-	26.8	40.8	-
Effect of suspension	Rear anti-roll bar bush removed	17.3	25.5	-0.5	26.4	40.9	0.1
	Both anti-roll bar bushes removed	16.5	18.2	-7.8	25.8	31.1	-9.7
	Stiff primary trailing arm bushes	17.8	27.4	1.4	26.8	42.6	1.8
	Soft primary trailing arm bushes	16.9	21.2	-4.8	26.0	35.5	-5.3
Effect of speed	5 mph	17.3	46.0	20.0	28.5	60.4	19.6
	10 mph	17.3	44.5	18.5	27.8	58.7	17.9
	15 mph	17.4	41.2	15.2	27.2	55.2	14.4
	25 mph	17.6	22.8	-3.2	26.0	36.5	-4.3
	30 mph	17.7	19.7	-6.3	25.9	32.5	-8.3
Addition of check rail	Checkrail added (standard clearance)	-16.8	-18.9	-44.9	0.5	-6.1	-46.9
	Checkrail added (large clearance)	-10.8	-11.0	-37.0	5.7	4.9	-35.9
Effect of friction	Wheel-rail friction 0.05	6.1	6.7	-19.3	18.0	19.7	-21.1
	Wheel-rail friction 0.10	9.3	9.7	-16.3	20.4	22.6	-18.2
	Wheel-rail friction 0.15	11.8	13.2	-12.8	22.2	26.2	-14.6
	Wheel-rail friction 0.25	16.1	17.6	-8.4	25.6	30.6	-10.2
	Wheel-rail friction 0.32	18.1	40.2	14.2	27.0	53.4	12.6
	Wheel-rail friction 0.35	18.8	41.0	15.0	27.5	54.0	13.2
Effect of lateral track stiffness	Rail-sleeper stiffness doubled	17.9	18.5	-7.5	20.6	22.4	-18.4
	Rail-sleeper stiffness halved	22.6	41.2	15.2	46.2	91.9	51.1
Rail condition	New rails	17.6	24.8	-1.2	27.2	38.2	-2.6
Comparison of vehicle type	Class 465 vehicle	19.1	43.4	17.4	27.0	56.9	16.1

Notes on table above:

1. The base case in the second row represents class 508 trains running at 20 mph (32 km/h). All other results are compared with this base case.
2. Results in green show an improvement. Results in red show a worsening.
3. The values in the third and fourth columns of the table are those predicted for wheelset 3 at sleeper zero and also the maximum values that occur slightly beyond sleeper zero.
4. The predicted *gauge* spread results assume a degree of initial widening caused by the passage of earlier wheelsets (calculated to be 13.2 mm).
5. For the run performed with new rails, the track *gauge* was reduced by 6 mm to account for the removal of the *high rail sidewear* measured at the derailment site.
6. The check rail was modelled for two cases: (1) at the standard check rail *gauge* of 1391 mm and nominal *track gauge* of 1435 mm; (2) at a larger clearance of 85 mm approaching the maximum clearance at which the check rail would still contact the back of the flange to remain effective.

RAIB SF-3.1.9.1
ISSUE : 1

URGENT SAFETY ADVICE

1. INCIDENT DESCRIPTION			
LEAD / INSPECTOR	Chris Hall	**CONTACT TEL. NO.**	
INCIDENT REPORT NO	RAID/519/USA/001	**DATE OF INCIDENT**	26 October 2005
INCIDENT NAME	Liverpool Central		
TYPE OF INCIDENT	Derailment of passenger train in tunnel		
INCIDENT DESCRIPTION	The rear bogie of a class 508 unit derailed whilst traversing the Liverpool Loop tunnel, between Lime Street and Central Station. Initial investigations point to the mechanism of derailment being the low rail wheel falling between the tracks, and subsequently the high rail wheel being forced over the rail by pressure from the first derailed wheel. The track has considerable areas of wide gauge. Multiple tie bars had been fitted, some of which have subsequently failed. There is evidence of considerable dynamic movement of the rails under traffic – see attached high rail photo.		
SUPPORTING REFERENCES			

2. URGENT SAFETY ADVICE	
USA DATE:	27 October 2005
TITLE:	Gauge widening
SYSTEM / EQUIPMENT:	Pre-stressed concrete-sleepered track part embedded in concrete base. Tie bars fitted but with varying quality and effect.
SAFETY ISSUE DESCRIPTION:	Insulators pushed out and rails cut into housings combined with extensive side-wear, permitting track gauge to widen, thus allowing potential for derailment.
CIRCUMSTANCES:	Sharp curved track in aggressive tunnel environment
CONSEQUENCES	Gauge widening allowing derailment
SOURCE:	RAIB site investigations
REGULATING ISSUES:	No issues
REASON FOR ISSUE	So that duty holders with similar track forms may check for potential similar details

USA SIGN-OFF			
INSPECTOR NAME:	Chris Hall	**CI / DCI NAME:**	Andy Savage
INSPECTOR SIGNATURE:	Chris Hall (signature)	**CI / DCI SIGNATURE:**	Andy Savage (signature)
DATE:	27 October 2005	**DATE**	27 October 2005


Photo attached to Urgent Safety Advice

This report is published by the Rail Accident Investigation Branch, Department for Transport.

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