Rail Accident Investigation Branch

Rail Accident Report

Autumn Adhesion Investigation
Part 3: Review of adhesion-related incidents
Autumn 2005

Department for Transport

Report 25 (Part3)/2006
January 2007

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.

Any enquiries about this publication should be sent to:

RAIB	Email: enquiries@raib.gov.uk
The Wharf	Telephone: 01332 253300
Stores Road	Fax: 01332 253301
Derby UK	Website: www.raib.gov.uk
DE21 4BA	

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

Review of adhesion-related incidents during Autumn 2005

Contents

Introduction

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

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

3 This report contains the findings of the RAIB investigation into the causes of adhesion related station overrun and Signal Passed At Danger (SPAD) incidents during autumn 2005.

4 The investigation examined:

- data on adhesion performance for the years 2000, 2004 and 2005;
- relevant Railway Group Standards (RGS);
- data from specific adhesion-related incidents;
- research on adhesion-related subjects from the UK and abroad;
- other information on adhesion-related issues supplied by the parties identified below.

5 For the purposes of this investigation, access was freely given by the following organisations to their staff, data and records:

- Network Rail;
- *Train Operating Companies* (South Eastern Trains[1], Southern Railway, South West Trains (SWT), c2c, Merseyrail and First ScotRail);
- *Rail Safety and Standards Board* (RSSB), who provided information from their research programme and data on adhesion-related incidents;
- train owners (Angel Trains, HSBC and Porterbrook);
- train manufacturers (Bombardier and Siemens);
- train equipment manufacturers (Knorr Bremse);
- AEA Technology who provide services to the railway industry in evaluating the performance of rolling stock;
- Interfleet in their role as a *Vehicle Acceptance Body* (VAB).

6 In addition, RAIB has consulted and exchanged information with the *Adhesion Working Group* (AWG), a cross-industry body that has also been investigating the causes of adhesion-related incidents in autumn 2005. The AWG has prepared a report, which was reviewed by RAIB during the course of its own investigation.

[1] Train services in Kent are now operated by 'Southeastern', the successor organisation to South Eastern Trains. As the latter operated services during Autumn 2005 and were consulted by the RAIB during the course of this investigation this report makes reference to South Eastern Trains where appropriate.

7 Appendices at the rear of this report contain:

- a glossary of acronyms and abbreviations (Appendix A);
- explanation of certain technical terms (shown in italics the first time they appear within the body of this report) (Appendix B);
- a list of relevant RGS current in autumn 2005 (Appendix C);
- an overview of magnetic brakes, which is a technology for stopping trains that is not used on main line railways in this country, but is used in other European countries (Appendix D);
- a comparison between the recommendations from the investigation undertaken by the AWG into adhesion-related incidents in autumn 2005 and the recommendations from this report (Appendix E).

8 Two terms are used throughout this report, 'wheelslide', and 'slip':

- **Wheelslide** refers to problems experienced by trains during braking, when wheel rotational speed is slower than the actual speed of the train. The extent of wheelslide can vary from 1-2% (wheels rotating at a slightly lower speed than the train's actual speed) through to 100% (wheels locked when train is moving). The converse issue during acceleration, when low adhesion can cause wheel rotational speed to be higher than actual train speed is referred to as 'wheelspin'. This report is only concerned with adhesion problems during braking.
- **Slip** refers to the parameters within which a *wheelslide prevention (WSP) system* permits train wheels to rotate below the real speed of the train (extent of slip). WSP systems are provided on trains to limit the extent of wheelslide and wheelspin by modulating braking or tractive effort. In braking, most modern WSP systems permit slip values up to a maximum of 20% of real speed before intervening to release brakes and allow wheel rotational speed to build up towards the real speed of the train.

9 Reference is also made in the report to levels of adhesion between wheel and rail. This is normally expressed as a coefficient of friction (symbol μ). The lower the value of μ, the lower the adhesion between wheel and rail. Typical values for μ for dry rail would be at least 0.20. In wet weather, this can fall to 0.10. Under severe low adhesion conditions, the value of μ can drop below 0.03. As trains rely on the coefficient of friction between wheel and rail to stop, the level of adhesion available is critical to the rate at which the train can decelerate. Many modern trains have four or five fixed braking rates available to the driver, the lowest of which will normally achieve a deceleration rate of $0.3m/s^2$ and the highest a rate of at least $1.2m/s^2$. Although the relationship is not exact, a braking rate of $0.3m/s^2$ can only be achieved if the value of μ is at least 0.03. The value of μ would need to be at least 0.12 to achieve an emergency braking rate of $1.2m/s^2$.

Summary of the report

Key facts about adhesion performance during autumn 2005

10 The immediate cause of the SPAD incidents that occurred at Esher on 25 November 2005 and Lewes on 30 November 2005 (which are the subject of Parts 1 and 2 of this investigation report) was poor adhesion between wheel and rail. Both trains involved had failed to stop within normally expected distances, despite the systems on the train performing in accordance with their specifications and the drivers correctly implementing the *professional driving policy* prevailing within the relevant Train Operating Company (TOC) at the time. Both trains had travelled a distance of approximately 3km from the time that the driver had first applied the brake. Stopping distances under normal circumstances would have been less than 2km.

11 These two incidents occurred against a backdrop of an increase in the number of adhesion-related SPAD incidents and a significant increase in the number of adhesion-related station overrun incidents on the national rail network during autumn 2005, as compared with autumn 2004:

	AUTUMN 2004	AUTUMN 2005
Adhesion-related SPADs	7	9
Adhesion-related station overruns	152	390

Figure 1: Adhesion-related SPAD and station overrun incidents - autumn 2004 and autumn 2005.

12 The purpose of this investigation has been to establish the causes of this increase in adhesion-related incidents in autumn 2005 and by so doing, identify ways in which short, medium and long-term performance can be improved.

Risk from adhesion-related incidents

13 When viewed from a historical perspective, the risk from adhesion-related incidents can be characterised as high in frequency but low in consequence. There have been very few accidents arising from low adhesion. The most significant adhesion-related accident occurred in November 1985, when two trains collided at Copyhold Junction in Sussex resulting in 40 people being injured, 11 of them seriously. Another low-adhesion accident occurred in November 1994 when a train ran into the buffer stops at Slough, causing the driver serious injuries.

14 However, the two near-miss incidents at Esher and Lewes in autumn 2005 demonstrate that the potential exists for a serious accident to result from low adhesion conditions. There were 6 incidents (including the Esher SPAD) where the length of the overrun exceeded 1000 metres and 18 incidents where the overrun was so severe that the driver continued to the next station rather than returning to the station that had been passed. There is scope for further action to address the risk arising from these severe incidents.

15 Based on historical experience, although adhesion-related incidents have rarely resulted in an accident, should an accident occur, the most probable outcome is a collision if a train fails to stop at a signal or derailment if a train runs through facing points at excessive

speed or fails to stop at a signal where *trap points* are located immediately beyond. While modern rolling stock has a high standard of crashworthiness, a train collision has the potential for fatalities and injuries. Train derailments at low speed may not carry the same potential for fatality and injury, but they can also lead to collisions if the derailed train obstructs an adjacent line.

Immediate causes, contributory factors and issues of concern

16 There is no single immediate cause of the increase in adhesion-related station overrun and SPAD incidents during autumn 2005. However, there are a number of causal factors:

- Significant lengths of low adhesion were experienced on a number of occasions during autumn 2005 and it is possible that they are now occurring more frequently than has been previously thought to be the case.
- A method for identifying low adhesion areas that was biased towards historical data rather than current conditions or risk.
- Different methods of rail head treatment being employed across the network, arising from uncertainty over the optimum method.
- Inconsistent performance in the prediction of days when the risk of low adhesion incidents was high.
- The application of sand is one of the most effective ways of modifying the level of adhesion available to trains experiencing difficulties. However, not all units are equipped with the facility to lay sand and some are specifically excluded by RGS GM/RT2461.
- The guidance value of 2kg/minute contained within RGS GM/RT2461 for maximum rate at which sand can be dispensed is based on a concern that sanding at higher rates may result in stationary or slow moving trains failing to operate track circuits because of excessive sand between the wheel and rail surface. However, there are circumstances under which sand can be applied at higher rates without compromising track circuit operation. There is no guidance on this subject available to TOCs, train owners or manufacturers.
- The TOCs' understanding of the characteristics of new rolling stock, which affected the way in which drivers were briefed about handling trains in low adhesion conditions and which was not optimal for the configuration of WSP and sanding equipment provided on modern trains.

17 Contributory to the performance experienced in autumn 2005 were:

- The absence of criteria within RGS on maximum braking distances under low adhesion conditions.

18 Several issues were identified that were neither causal nor contributory to the events of autumn 2005, but nonetheless need to be addressed in order to ensure that the issue of adhesion and train performance is addressed in an holistic manner:

- There is a need for further research into the mechanisms that create severe low adhesion conditions.

- There is no validated model available to test or optimise the performance of WSP systems that is capable of simulating the performance of the whole train or take into account the impact that key items of equipment such as sanding have on stopping performance.
- Further consideration needs to be given to establishing the optimum slip parameters for WSP systems under sustained low adhesion conditions. This does not mean that the current parameters are wrong but rather that they have still not been proven to be correct.
- In Britain, train braking is entirely dependent on available adhesion between wheel and rail. Magnetic brakes, currently used in some European countries, offer another means for slowing trains in emergencies.
- Investigation of low adhesion incidents is not performed in a consistent or systematic manner. If undertaken consistently in future, this will help to provide valuable data on the causes of such incidents.
- The data gathered by modern rolling stock represents a potentially valuable source of intelligence on adhesion conditions and could possibly be exploited to a greater degree than is currently the case.

Recommendations

19 Recommendations can be found in paragraph 283 and have been divided between those that can be implemented in the short term and those that can be implemented in the medium/long term. They relate to the following areas:

- measuring and understanding low adhesion conditions;
- methods for determining rail head treatment, including where and how to treat;
- short term and real time prediction of low adhesion conditions including the use of the capabilities of modern rolling stock to provide real time data on adhesion conditions;
- enhancements to RGS addressing braking and sanding parameters and configuration;
- configuration of WSP systems and the simulation of WSP performance;
- testing of alternative methods of stopping trains that do not solely rely on the wheel/rail interface;
- rolling stock sanding parameters and configuration;
- development of appropriate professional driving policies;
- investigation into adhesion-related incidents.

20 The RAIB sent eight short-term recommendations to relevant duty holders on 6 July 2006 in advance of formal consultation to enable relevant parties to consider them and to take action that they felt to be appropriate for autumn 2006.

The issue

Low adhesion incidents in autumn

21 Low adhesion is a level of adhesion between the wheel and the rail that has the potential to extend the braking distance beyond that required under normal conditions. Incidents caused by low adhesion occur most frequently during autumn. The phenomenon affects railway networks throughout the world. Low adhesion incidents comprise station overruns and SPADs, usually caused by the presence of contamination on the rail head which prevents the wheels from obtaining adequate adhesion during braking. Leaf residue is the most common contaminant.

22 The presence of contamination on the rail head can also cause loss of *train detection* when the contaminant acts as a barrier between the train wheels and the rail surface, preventing the wheels from operating the *track circuit*.

23 Although the number of adhesion-related incidents increases during autumn, there are significant variations year on year. Figure 2 shows the numbers of adhesion-related SPADs, adhesion-related station overruns and failures to operate track circuits for the six autumns from 2000 to 2005. In autumn 2005 there was a small increase in the number of SPADs and a significant increase in the number of station overruns in comparison with the previous year (see also Figure 1), while the number of failures to operate track circuits was similar. The number of SPADs and failures to operate track circuits was below the average for the preceding five years, but the number of station overruns was higher in 2005 than in any of the preceding five years.

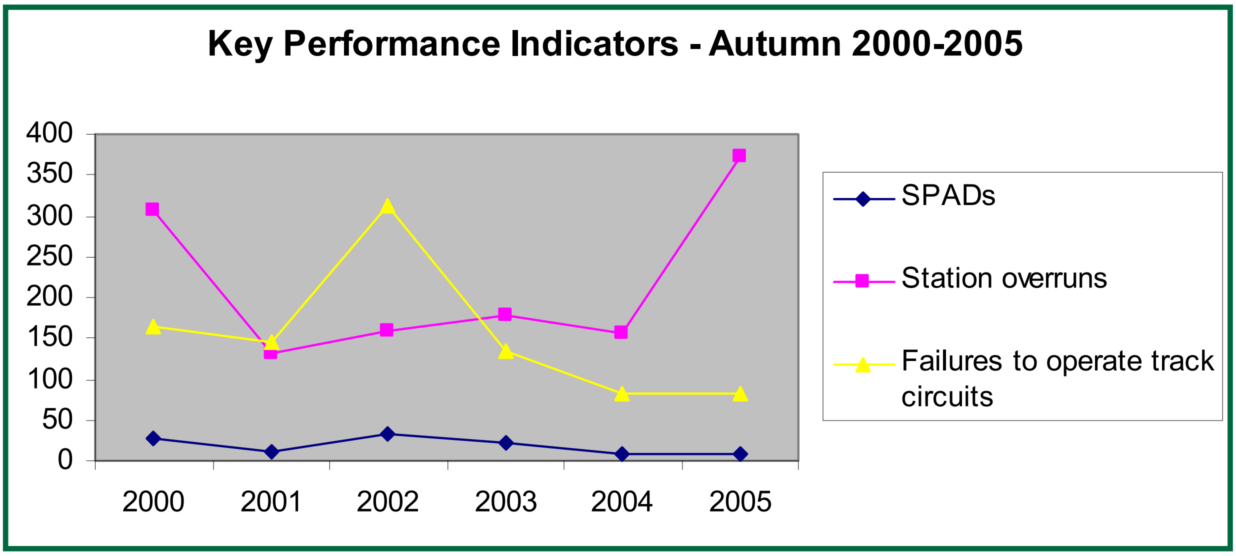


Figure 2: Adhesion-related incidents - autumn 2000 to autumn 2005.

24 This investigation has focused on adhesion-related station overrun and SPAD incidents. These incidents occur only in locations where trains are required to stop, in contrast with failures to operate track circuits which can occur anywhere on the network where contamination is severe enough to prevent electrical contact between wheel and rail. In view of the steady decline in incidents involving failures to operate track circuits, they have not been considered in this investigation. However, some of the measures employed to address the problem of railhead adhesion in the autumn have an effect on the issue of failure to operate track circuits. Sometimes the effect is beneficial; high pressure water

jetting cleans the surface of the rail and promotes conductivity between wheel and rail. The application of sand and *Sandite* (sometimes referred to as Electragel) if not properly controlled, can act as a barrier between wheel and rail which is sufficient to prevent the conductivity necessary for track circuit operation. Sandite now comprises steel particles and sand suspended in a gel, with the metal being included to improve track circuit operation. Service trains only dispense sand.

The parties involved

25 The parties directly affected by low adhesion are Network Rail and the TOCs.

Location of adhesion-related problems

26 Although adhesion-related problems can occur virtually anywhere on the network, there are some locations that are more vulnerable than others (paragraph 70 and Figures 7a and 7b). Table A in the s*ectional appendices* provides information on specific sites where exceptional rail head conditions may be encountered. The TOCs produce detailed briefing notes for drivers that include information on areas where low adhesion may occur. Although these notes draw upon the information provided in the sectional appendices, they may include additional sites that the TOC wishes to highlight to its drivers. Falmer bank, the site of the adhesion problems that caused the SPAD at Lewes on 30 November 2005, is an example of a location that is not included as a low adhesion site in the relevant sectional appendix but is highlighted to drivers as such in the briefing note for the route.

27 Esher, the location of an adhesion-related SPAD on 25 November 2005, had not been identified as a low adhesion location. The fast line between Woking and Surbiton was not treated to counter the effects of low adhesion because, prior to autumn 2005, there had been no experience of low adhesion incidents in that area.

Factors that can affect adhesion

28 The presence of contaminant on the rail surface is one of the key causes of adhesion problems. The most common source of contamination is leaf-fall onto the line and the subsequent crushing of leaves into a soft or hard 'teflon'-like residue.

29 The AWG has prepared a low adhesion manual[2], which lists the following causes of low adhesion:

- general moisture/dampness, particularly in cuttings, mixed with contaminants such as railhead rust or leaf residue;
- light rain/drizzle after a dry period mixed with contaminants such as rail head rust or leaf residue;
- ice on the rail;
- dust, particularly coal dust;
- spilled diesel fuel and lubricating oils from locomotives and *diesel multiple units*;

[2] *Adhesion Working Group, 'Managing Low Adhesion', Third Edition, September 2004.*

- leaking hydraulic fluid from track machines;
- defective rail mounted flange lubricators (dispensing excessive amounts of grease);
- airborne kerosene near airports and chemicals near industrial sites.

30 Not all of the items on the list are associated with the autumn period alone and not all of them are within the control of the railway. Leaf-fall is not the only factor that influences the level of adhesion available. Research undertaken by the University of Sheffield[3] highlights water as being the most important cause of low adhesion and particularly when small amounts of water are present (heavy rain will clean the rail). Water on clean rail does not create adhesion problems for trains in braking but a small amount of water in combination with contamination does.

31 Some of the factors that cause low adhesion are localised and transient in nature. This makes it difficult to predict exactly when conditions will deteriorate to the point where adhesion-related incidents may occur. Changes in humidity can result in damp rail surfaces for a relatively short period of time; once the surface of the rail dries the contamination alone may not cause adhesion difficulties for trains. The likelihood of an adhesion-related incident occurring during this time is also affected by whether the rail head has been treated recently and by the requirement for trains to stop in a location where low adhesion conditions are present. The incident at Lewes (described in part 2 of this investigation report) provides a good illustration of the critical part that dampness plays in creating or exacerbating low adhesion conditions.

32 Although there is extensive knowledge regarding the causes of low adhesion, there remains some uncertainty over the mechanisms that create severe low adhesion conditions. The incident at Esher reported as Part 1 of this investigation resulted in an overrun of approximately 1050 metres, yet no contamination was visible to the naked eye and none was found on swabs taken from the rail head. This does not mean that contamination was not present, but rather that detection of the causes of contamination is sometimes problematic.

Management of low adhesion

Infrastructure Manager

33 Low adhesion is managed through an extensive set of measures implemented by Network Rail and the TOCs. The requirements are laid down in RGS GE/RT8040. This RGS obliges the Infrastructure Manager (i.e. Network Rail for the main line rail network) to control the risk of low adhesion to a level that is as low as reasonably practicable, by:

- having processes in place to identify locations where low adhesion might occur;
- publishing details of low adhesion locations in the Sectional Appendices;
- leading development of site-specific plans to reduce the likelihood of low adhesion occurring;
- leading development of action plans to manage low adhesion at new sites;
- monitoring the performance and reviewing plans to ensure effective action is taken.

[3] New Rail Materials and Coatings, Report for the Rail Safety & Standards Board, REF. RRUK/A2/1,University of Sheffield, July 2003

34 Network Rail implements the requirements of the RGS with its own *Company Procedure*, NR/SP/OPS/096[4]. The procedure sets out the steps taken by Network Rail to identify high-risk adhesion sites comprising a risk assessment approach or review of historical records. Feedback from traincrew or infrastructure maintenance staff, analysis of *on train monitoring and recording* (OTMR) equipment, commissioned research, analysis of data recorders and local knowledge can be used as input. Using the historical records approach, sites will only be published in the sectional appendix if there have been more than 2 SPADs or more than 4 overruns in the last three years as a result of leaf-fall.

35 Network Rail has various ways of controlling the risk at low adhesion sites. Vegetation management is employed to eliminate the sources of leaf-fall. This technique, which involves cutting back or cutting down trees and bushes, is only under Network Rail's control for vegetation growing on the railway side of the boundary fence. Landowners of property adjacent to the railway are often unwilling to lose the screen provided by trees and bushes, in which case the leaf-fall will continue to affect railway infrastructure.

36 Network Rail seeks to eliminate low adhesion conditions during the leaf-fall season by treating the rail surface. *Multi Purpose Vehicles (MPVs)* and Rail Head Treatment Trains clean the rail head using high pressure water jets. In some parts of the network during 2005, the MPVs also applied Sandite to the rail surface to enhance adhesion. At known problem sites, static Traction Gel applicators are employed, which are triggered by passing trains and use the train wheels to apply a small amount of Sandite over the affected section of line.

37 On a tactical level, Network Rail used the specialist environmental and weather organisation, ADAS UK Ltd, to predict leaf-fall patterns in 16 geographical areas on a daily basis during autumn 2005. When severe conditions are predicted, additional measures are employed to improve wheel/rail adhesion in known problem areas. Those measures include increasing the number and/or extent of treatment programmes using high-pressure water jets and Sandite, the use of Sandite in areas where water jetting alone is normally used and the provision of 'rapid response' gangs to deal immediately with adhesion problems as they occur, using rail surface scrubbers and manually applying sand. As the treatment of the rail head in this way involves Network Rail staff going onto the 'live' railway where they are exposed to the hazards of train movement, the activity is subject to rigorous risk assessment. Network Rail also strengthens its Route Control arrangements during the autumn period with the use of an individual designated as adhesion controller whose responsibility is to monitor adhesion conditions, deal with low adhesion reports and take action to ensure that low adhesion conditions are dealt with expeditiously.

38 Network Rail liaises with TOCs over the plan for rail head treatment and there is a process in place that promotes feedback on adhesion issues from TOCs to Network Rail. As described in paragraph 34, Network Rail has a process in place for determining whether information on low adhesion sites provided by the TOCs justifies their inclusion within the relevant sectional appendix.

[4] *Network Rail, NS/SP/OPS/096 'Determining High Risk Sites for Low Rail Adhesion (formerly RT/D/P/096), Issue 1, Network Rail, August 2004.*

Train Operating Companies

39 RGS GE/RT 8040 obliges TOCs to:

- cooperate with the Infrastructure Manager to reduce the risk arising from low adhesion;
- ensure drivers are trained and competent to recognise those locations where low adhesion may occur and to use appropriate driving techniques when low adhesion conditions are encountered;
- consider the provision of train borne systems to improve braking performance under conditions of low adhesion including optimised WSP and sanding equipment;
- consider using on-train systems to detect wheelslide activity and alert the driver;
- consider providing remote monitoring systems to alert drivers to low adhesion conditions.

40 TOCs liaise with Network Rail in order to provide input to each autumn's plans for rail head treatment. There is also a critical process of real time feedback during periods of low adhesion when train drivers advise signallers about problems they have encountered, which can then result in warnings being issued to drivers to approach the area with caution and additional railhead treatment in the problem area.

41 TOCs employ a range of measures to ensure their drivers are competent to deal with low adhesion conditions. Training methods include the use of 'skid pan' training and simulators.

42 In addition to training, TOCs brief drivers on driving techniques for low adhesion conditions prior to the start of the leaf-fall season. In autumn 2005, the briefing generally emphasised the need for 'light and early' braking, although there was some variation in the techniques adopted by different TOCs for managing low adhesion.

43 One of the principal contributions made by TOCs to managing low adhesion is to operate rolling stock equipped with systems designed to cope with low adhesion such as WSP and sanding. In autumn 2005, approximately 90% of rolling stock operating over the national railway network was equipped with a WSP system. The availability of WSP (and sanding – see paragraph 45) has resulted in less reliance on driver action to control wheelslides, the emphasis being on allowing the WSP system and sanding to manage train braking in low adhesion conditions.

44 The WSP system works by detecting wheelslide and regulating the rotational speed of the wheels by means of the controlled release and re-application of the brakes. This control mechanism limits the extent of slip to around 17-20% (i.e. the difference between the actual rotational speed of the wheels and the rotational speed they would have achieved had they not been sliding is not permitted to exceed 20%).

45 Trainborne sanding equipment complements the WSP system. The application of sand is beneficial for adhesion in both traction and braking. Sanding equipment has been available on multiple units since the mid 1990s and more than 80% of multiple units operating over the national railway network are equipped with sanders. Sanding systems have evolved and different systems are currently in use. The original equipment was activated by the driver and consisted of a single application for a limited duration ('one-shot' sanders). The majority of modern multiple units are equipped with automatic sanding when WSP activity occurs during braking and manual sanding under the control of the driver when wheel slip is encountered in traction. The point at which automatic sanding commences varies between different types of multiple unit and is dependent on the *brake step* selected

by the driver. Other measures are adopted by TOCs selectively to address low adhesion conditions. Some TOCs adopt an autumn timetable on routes that are particularly susceptible to low adhesion conditions, e.g. Southern on the East Grinstead line. Some TOCs also operate longer trains during the autumn. While this is not possible during peak hours because maximum demand for stock is present at this time, trains can sometimes be strengthened off peak. The relevance of operating longer trains to coping with low adhesion conditions is explained in paragraph 66.

Characteristics of low adhesion incidents

46 Parts 1 and 2 of this report provide details of two adhesion related SPAD incidents that occurred at Esher on 25 November 2005 and Lewes on 30 November 2005. Figure 3 contains details of eight station overruns and one other SPAD that occurred during autumn 2005.

Details
Train 2L69 (class 450 EMU) approached Farnborough station at approximately 70 mph (112 km/h). Driver selected step 1 brake in accordance with 'light and early' philosophy. WSP became active immediately and train speed fell only slowly. After 15 seconds the driver selected step 2 braking and then steps 3 and emergency in rapid succession, but the train overshot the station by 400m.
Train 2N80 (class 450 EMU) approached Wanborough station at 15 mph (24 km/h), the driver having completed a light and early brake application to bring the train speed down for stopping. Driver selected step 1 brake for final stop and WSP became active immediately. Step 2, step 3 and emergency brakes were used in the space of 30 seconds but the train overshot the station by 20m.
Train 2N50 (class 377 EMU) approached Emsworth station at approximately 50 mph (80km/h) and the driver made a light and early step 1 brake application. WSP successively activated on the three vehicles on the train. The driver selected steps 2, 3 and emergency braking over the space of 15 seconds but train overshot station by 80m. Train had taken approximately 1000m and 57 seconds to stop.
Train 1E69 (class 377 EMU) approached Horley station at approximately 70 mph (112 km/h). The driver made a step 1 brake application earlier than normal because of wet and windy conditions. Within four seconds, WSP activity commenced on all four vehicles. The driver selected step 2 braking and then within 10 seconds had moved straight to emergency braking, but train overshot station by approximately 80m. Train had taken approximately 1500m and 70 seconds to stop.
Train 2C78 (class 377 EMU) approached Earlswood station at approximately 45 mph (73km/h). The driver selected step 1 braking earlier than usual because of the wet and windy conditions. All four vehicles experienced WSP activity. The driver released and reapplied the brake and WSP activity recommenced. Steps 2 and 3 braking were selected in rapid succession, but the train overshot the station by approximately 40m.
Train 1R73 (class 375 EMU) approached Deal station and the driver applied step 1 brake early because of drizzly conditions. With train speed at 37 mph (58 km/h) WSP activity commenced on all three vehicles. The driver selected brake steps 2, 3 and emergency but the train not only overshot Deal station but also passed signal EBZ40 at danger by 60m. The train had taken 680m to stop from the time that WSP had become active.
Train 2J75 (class 375 EMU) approached Nutfield station at approximately 50 mph (80 km/h. Driver applied step 1 brake approximately 800m from the station. WSP activity occurred on all vehicles immediately and the driver rapidly moved into brake step 3 and then emergency shortly after. The train overshot the station by approximately 1200 metres, having taken 2000 metres and 135 seconds to stop. (This equates to an average braking rate of $0.18m/s^2$).
Train 2U12 (class 465 EMU) approached Bexleyheath station at approximately 45 mph (73 km/h). Driver applied step 1 brake in accordance with the light and early philosophy. WSP activity commenced on all vehicles immediately and the driver moved rapidly through the brake steps to emergency but deceleration remained extremely limited. The train overran the station by approximately 1000 metres.
Train 2A07 (class 377 EMU) approached Stoats Nest Junction (near Coulsdon) at approximately 70 mph (112 km/h) and the driver made an early step 1 brake application to stop at Purley station because of slippery conditions. WSP became active immediately. Over the next 20 seconds the driver moved through the brake steps to emergency brake, but speed only reduced to 63 mph (101km/h) by Purley station. Shortly after running through Purley station, the train brakes started to work effectively and the train stopped 440 metres beyond Purley station platform. Minimal rail head contamination was found.

Figure 3: Case studies of adhesion-related incidents in autumn 2005.

47 The incidents described in Figure 3 indicate that the following features were associated with severe low adhesion incidents in autumn 2005:

- On initial application of the brake in step 1, there is no discernible reduction in speed. Depending on the characteristics of the rolling stock, there may also be an indication of WSP activity through the illumination of the desk light or significant fluctuations in speed registered on the speedometer. Where WSP is fitted, the driver may hear the sound of the *blowdown valves* operating as air is released from the braking system.
- When drivers increase the brake to step 2, there may be only limited effect on train speed. If fitted, WSP continues to operate and automatic sanding may commence, but the braking rate of the train is below the driver's expectations.
- Increasing the brake to step 3 and emergency results in some reduction in speed, but at a lower rate than would be expected. By this stage, the driver will have realised that the train is not going to achieve its targeted stopping point, whether that is a station or signal, or that it is not going to achieve a targeted speed reduction for a permanent or temporary speed restriction. In the case of an impending SPAD incident, the driver may now make an emergency call to the signaller.
- Eventually, the train stops, by this stage beyond the targeted stopping point. The way in which the train stops varies and this is likely to be dependent on the length of track over which low adhesion conditions are present. A sudden stop will result from the train encountering rail that is not contaminated.

Response to low adhesion incidents

48 The response to low adhesion incidents is dependent on the seriousness of the incident:

- If a driver has experienced difficulty in stopping, RGS GE/RT8000 (the *Rule Book)* requires that he or she must alert the signaller if the area is not one of those listed in the sectional appendix (paragraph 34). If the location is listed in the sectional appendix and railhead conditions are exceptionally poor the driver must also alert the signaller.
- The Rule Book mandates a range of actions to be taken by the signaller on advice from a driver of low adhesion conditions. The action is dependent on the location of the problem:

Location where conditions apply	**Action to be taken**
Approach to a stop signal	Arrange for the driver of each approaching train to be told of the circumstances unless showing a proceed aspect
Manned level crossing within the overlap of the signal	Close the crossing to road traffic **before** each train approaches
AHBC level crossing	Select the non-stopping mode (where provided)
Approach to a platform	Arrange for the driver of each train booked to call to be told about the circumstances
Dead-end platform	Arrange, if possible, for the platform to be taken out of use

- Network Rail's route controller will arrange for the relevant section of line to be inspected as soon as a *Mobile Operations Manager* (MOM) can be deployed to site. If necessary, the rail head will be subject to additional treatment (local application of sand or Sandite, scrubbing of rail surface). If no contamination is found, the driver of the next train to pass through the area will be asked to undertake a controlled stop in order to prove that stopping conditions are normal. If they are not, further sanding and scrubbing takes place until normal stopping conditions are established.
- The requirement to restore railway operations as quickly as possible after an incident means that there is limited time available for a comprehensive determination of cause. Because of this, wheel swabbing is rarely carried out and determination of the presence or otherwise of contamination on the rail head is limited to a visual inspection by the MOM. Only if the MOM sees contamination will swabs be taken. In 45% of the adhesion related incidents occurring in autumn 2005, no rail head contamination was observed by the MOM. Among the incidents where no contamination was seen were two where the length of overrun exceeded 1,000 metres.
- Swabs are sent to Scientifics Ltd for analysis. They have the capability to perform microscopy, x-ray fluorescence, gas chromatography and mass spectrometry tests in order to identify evidence of vegetation, silicon, hydrocarbons, and the specific detail of other organic contamination. This may help to prove the presence or otherwise of the designated contaminant although there is no way of using the results to determine the actual level of adhesion that was available on the day.
- For low adhesion events that result in accidents or involve signals being passed at danger, Network Rail and the relevant TOC conduct an investigation in accordance with the requirements of RGS GO/RT3252 (Signals Passed at Danger). Investigations have been conducted into the incidents at Esher and Lewes.

The Investigation

Investigation process

49 The starting point for the investigation was the initial findings into the low adhesion SPAD incidents at Esher on 25 November 2005 and Lewes on 30 November 2005. The purpose of Part 3 of the investigation was to establish the reasons why the number of low adhesion incidents during autumn 2005 was much higher than in the preceding year with a view to making recommendations that would help to minimise the number of adhesion-related incidents that occur in future.

50 The key elements to the investigation comprised the following workstreams:

- Data analysis of low-adhesion incidents for the years 2000, 2004 and 2005. The purpose of the analysis was to understand the characteristics and circumstances of each incident occurring in these three years. The year 2000 was chosen because it was the worst year for adhesion-related incidents in the five years before 2005. The year 2004 was chosen because it was the best year for adhesion-related incidents in the five years before 2005. In addition, the TOCs that operate services in Kent, Surrey, Sussex and Hampshire were running their new and old fleets alongside each other in 2004; the only year when direct comparisons between the performance of new and old fleets could be made.
- Analysis of infrastructure issues, targeted at understanding the causes of low adhesion, the steps taken by the Infrastructure Manager to mitigate the risk and relevant research findings.
- Analysis of rolling stock issues, targeted at understanding the range of systems relevant to low adhesion management such as WSP, sanding and braking, the standards governing performance of those systems and the processes in place for testing WSP systems. This workstream also examined research in this area.
- Analysis of operations issues, targeted at the link between the characteristics of rolling stock and the advice given to drivers on how trains should be handled in low adhesion conditions. This workstream also examined the processes applied to procuring and approving new rolling stock.

51 Throughout the course of the investigation, the inter-relationship between infrastructure, rolling stock and operations has been a constant theme and the division of the investigation into separate areas has not precluded consideration of system and interface issues.

Sources of evidence

52 The data review for 2000, 2004 and 2005 was based on the daily incident logs prepared by Network Rail's National Control Centre, supplemented by information from the RSSB's *Safety Management Information System* (SMIS).

53 Meetings have been held with Network Rail at headquarters and route level to discuss railhead treatment policy and practice. The information obtained has been supplemented with data provided by the AWG. The RAIB has exchanged information with the AWG and met with their representatives to review progress and share thinking. The RAIB has also reviewed the report prepared by AWG into the events of autumn 2005.

54 Meetings have been held to examine the specification, characteristics and performance of modern rolling stock with TOCs (SWT, Southern, South Eastern Trains, c2c, Merseyrail and First ScotRail), the rolling stock manufacturers (Bombardier and Siemens) and a manufacturer of braking, sanding and WSP systems (Knorr Bremse). Meetings have also been held with AEA Technology to discuss the operation of the simulator they use to test the performance of WSP systems, and with Interfleet, to discuss the rolling stock approvals process.

55 Information on training and briefing to drivers has been supplied by the TOCs identified above and South Eastern Trains and First Group (jointly with Network Rail) provided their own assessments of performance during autumn 2005[5].

56 Network Rail and the TOCs have provided information on practices followed in the aftermath of low adhesion incidents.

57 RSSB has provided information on ongoing research into various aspects of low adhesion management and on RGS and *Technical Specifications for Interoperability (TSI)*.

Key evidence

58 Key items of evidence are:

- data on autumn low adhesion incidents for 2000, 2004 and 2005;
- the OTMR downloads from trains involved in low adhesion incidents;
- documentation supplied by SWT and Southern on the specification, design, manufacture and testing of their new-build rolling stock and on their briefing of drivers on techniques for handling low adhesion incidents;
- the methodology and pass criteria applied to the testing of WSP systems on the *WSPER®*;
- the report issued by the AWG into the events of last autumn.

[5] Adhesion Working Group, 'Report of an independent review of low adhesion incident performance during autumn 2005', April 2006

Analysis

Review of data

Introduction

59 This section:

- provides some basic data regarding adhesion-related incidents, including analysis of the distribution of events:
  - throughout the autumn period;
  - by overrun distance;
  - by length of train;
  - by time of day;
  - by geography.
- analyses the distribution of adhesion-related events by rolling stock fleets;
- assesses whether modern rolling stock fleets are more susceptible to adhesion-related events than the stock that they replaced.

Data on adhesion-related incidents

60 Figure 4 shows the distribution of adhesion-related SPADs and station overruns from 1 October to 31 December for the years 2000, 2004 and 2005 (see paragraph 50 for an explanation of why these three years were chosen).

61 The data sources were identical for each of the three years (paragraph 52) and reporting procedures for adhesion-related incidents have not changed significantly since 2000. Both of these factors provide a degree of assurance on the dependability of the data.

62 The pattern of events is clearly different between the three years:

- 2000 had one pronounced peak and relatively few days with no incidents from the beginning of November;
- 2004 had one pronounced peak and a very low level of occurrence from the beginning of November;
- 2005 had three pronounced peaks. It was the most erratic of the three autumns; days with no events were scattered at frequent intervals as were days with a high number of events.

63 Figure 4 shows that each of the three autumns produced a different occurrence profile. The industry cannot rely on past experience to guide it on such matters as the timing or extent of peaks.

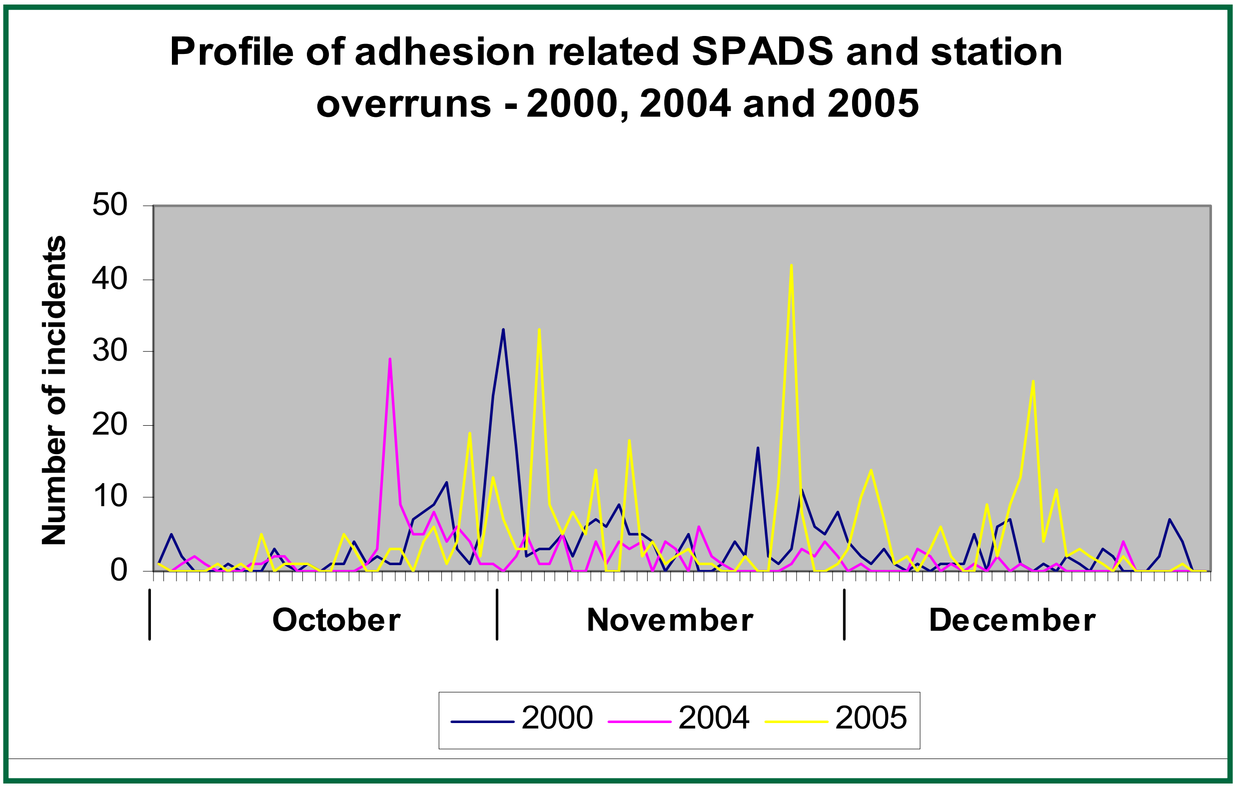


Figure 4; Profile of adhesion-related incidents - autumn 2000, 2004 and 2005.

Length of overruns

64 In autumn 2005, the extent of the overruns varied from 1 metre to 2000 metres. The graph presented in Figure 5 shows the range and distribution. The equivalent data for 2000 and 2004 have been included and show that the distribution of incidents is broadly similar for the three years. For station overruns, the figures may slightly underestimate the extent of the overrun because the measurement is taken from the end of the platform. In some cases, the driver's targeted stopping point will have been an intermediate point along the platform rather than the end.

65 Incidents labelled 'Fail to Call' in Figure 5 relate to those where the driver has decided to continue to the next station rather than return to the station that has just been overshot.

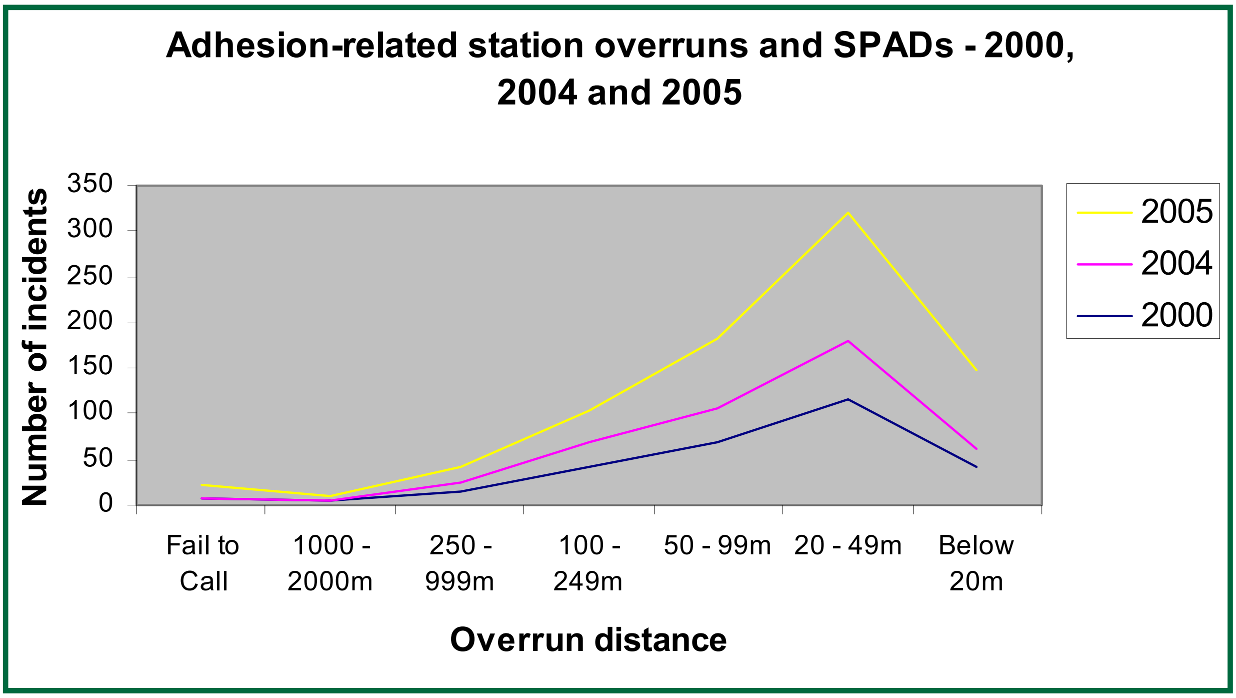


Figure 5: Distribution of length of overrun, 2000, 2004 and 2005.

Length of trains involved in overruns

66 In autumn 2005, detail on train formation was available for 375 adhesion-related incidents (368 station overruns and 7 SPADs). Of these 375 incidents, 325 (87%) involved trains of five vehicles or less. In 2004, the figure was 83%. Ideally, these figures would be considered in the context of the percentage of trains that are operated in formations of five vehicles or less, but this figure is not readily available. In talking with drivers and their managers, the view has been expressed that shorter trains can take longer to stop in low adhesion conditions and this is a generally (if not universally) held belief within the industry. One of the functions of WSP systems is to *condition* the rail head (paragraph 141), which improves adhesion for following wheels. A review of on-train data for the Esher and Lewes incidents showed that better braking performance was achieved at the rear of each train involved. There is thus evidence that the longer the train, the greater will be the benefit from *conditioning*.

Time of day when overruns occur

67 Figure 6 shows the distribution throughout the day of adhesion-related incidents for 2000, 2004 and 2005. Years 2000 and 2005 show a similar occurrence profile between 00:01 hrs and 20:00 hrs. The 2004 occurrence profile is similar to the other two years until 16:00, after which there is a notable decline in occurrences, not matched by experience in 2000 and 2005.

68 The relatively low level of occurrence between 00:01 hrs and 06:00 hrs is proportionate to the amount of rail traffic that is operating at the time. The morning peak period sees the highest number of adhesion-related incidents in all three years, but occurrence levels in the evening peak hours are not noticeably higher than those in off-peak periods. In 2005, the numbers of incidents occurring between 21:01 hrs and 22:00 hrs was higher than in any of the evening peak hours, despite there being fewer trains operating at this time of day. However, longer trains operate in the peaks, which may help to reduce the probability of an overrun occurring.

69 Damp rail head conditions can occur at any time of day, but changes in humidity can often occur in the period around dawn creating the damp conditions that can exacerbate the effects of contaminants present. There is often a sparse train service overnight (if any at all) and this means that contamination is not being disturbed or removed by passing trains in the period before dawn. These factors may help to explain why the highest rate of occurrence of adhesion-related incidents is in the morning peak period, although the detrimental effects should be offset by rail head treatment which takes place in the early hours of the morning as well as from mid-morning to early afternoon. It is possible that the lower levels of occurrence around the middle of the day and early afternoon reflect the beneficial effects of the second treatment. This might also explain why the numbers of incidents do not fall significantly in the late evening, as the effects of the second treatment have worn off by this time.

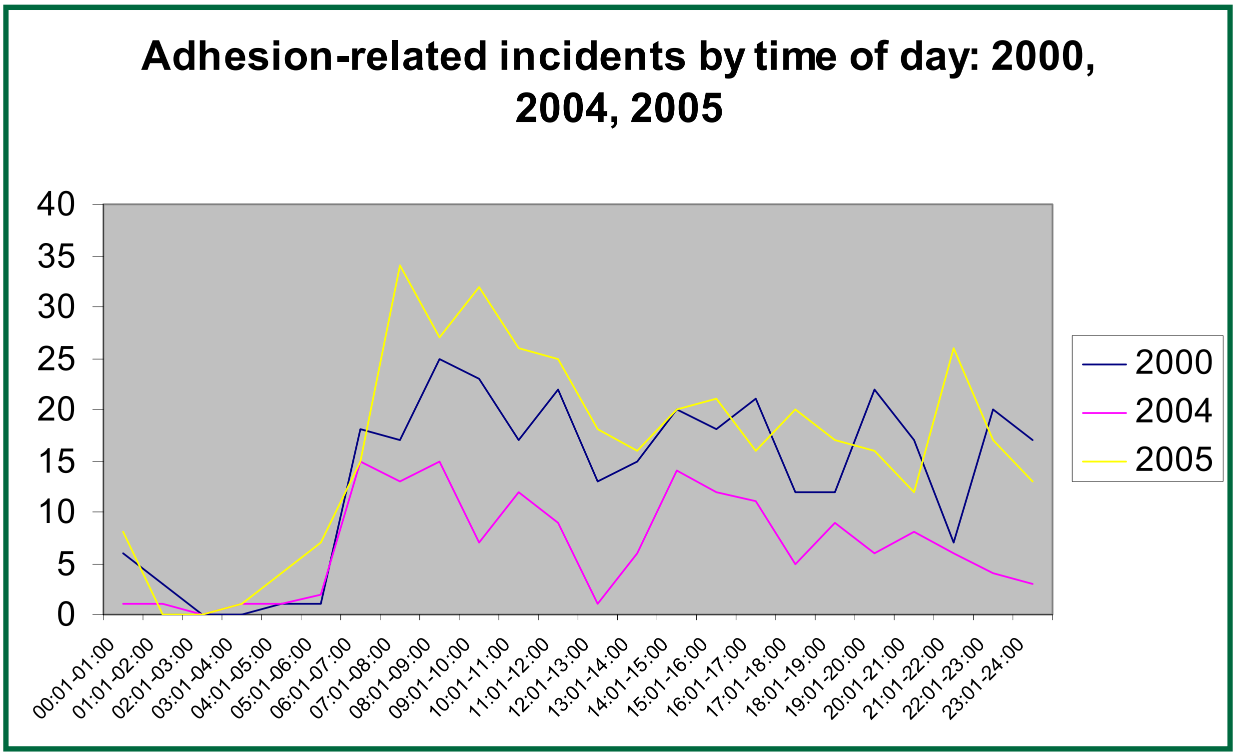


Figure 6: Distribution of adhesion-related incidents by time of day, 2000, 2004 and 2005.

Location of overruns

70 Figures 7a and 7b shows how the adhesion-related incidents that occurred in 2004 and 2005 were distributed throughout the country. It is evident from the maps that there was a polarisation towards the south east and Scotland in 2005 as well as consistent clustering of incidents in the north west. It is also apparent that some parts of the network experienced negligible numbers of incidents or none at all, confirming that low adhesion conditions are not entirely random events and that certain factors do make specific locations vulnerable to SPADs and station overruns during the autumn period. While there is some correlation between numbers of incidents and intensity of train service, the relatively low level of incidents in the Midlands indicates that this is not the governing factor.

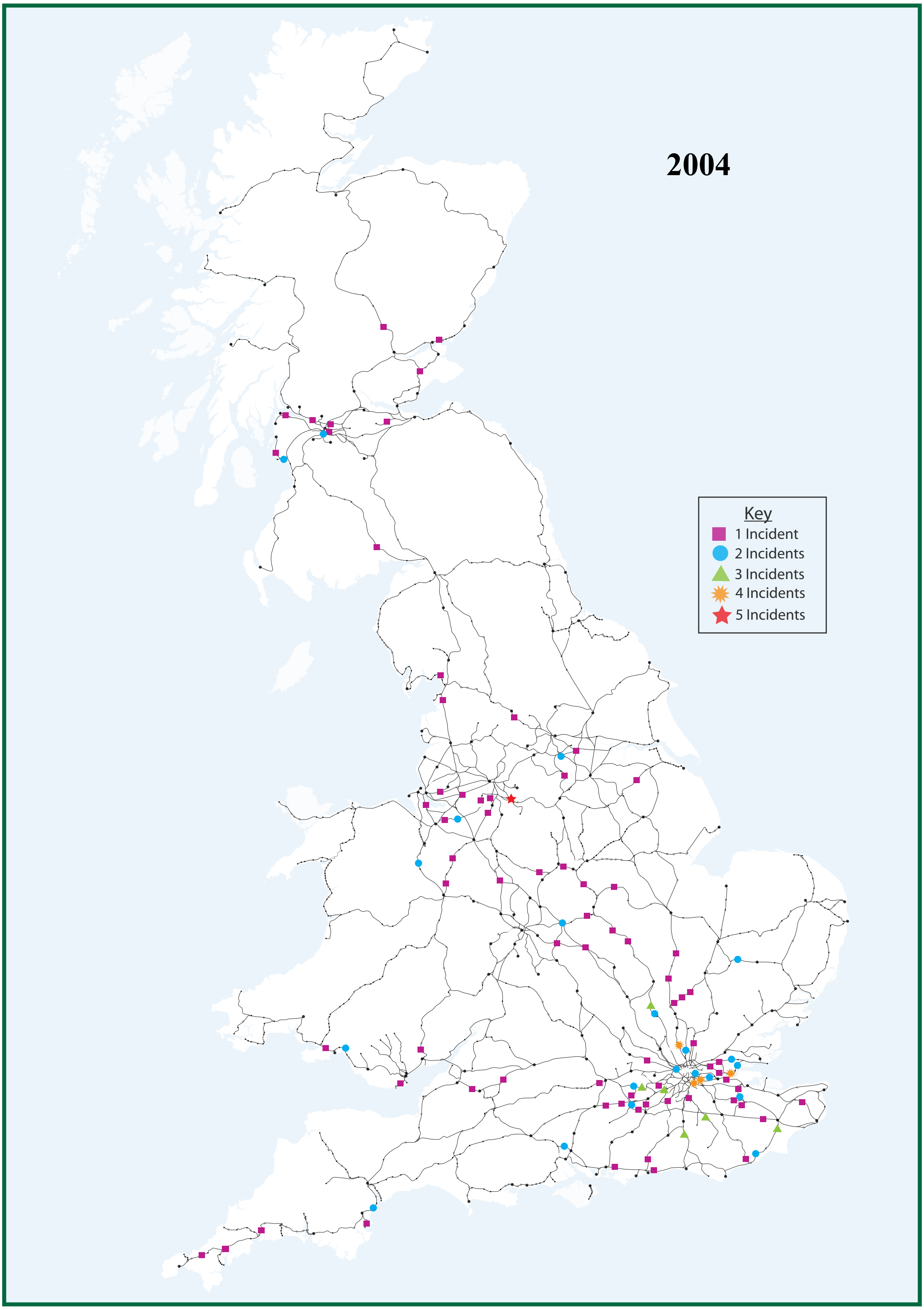


Figure 7a: Distribution of adhesion-related incidents - 2004.

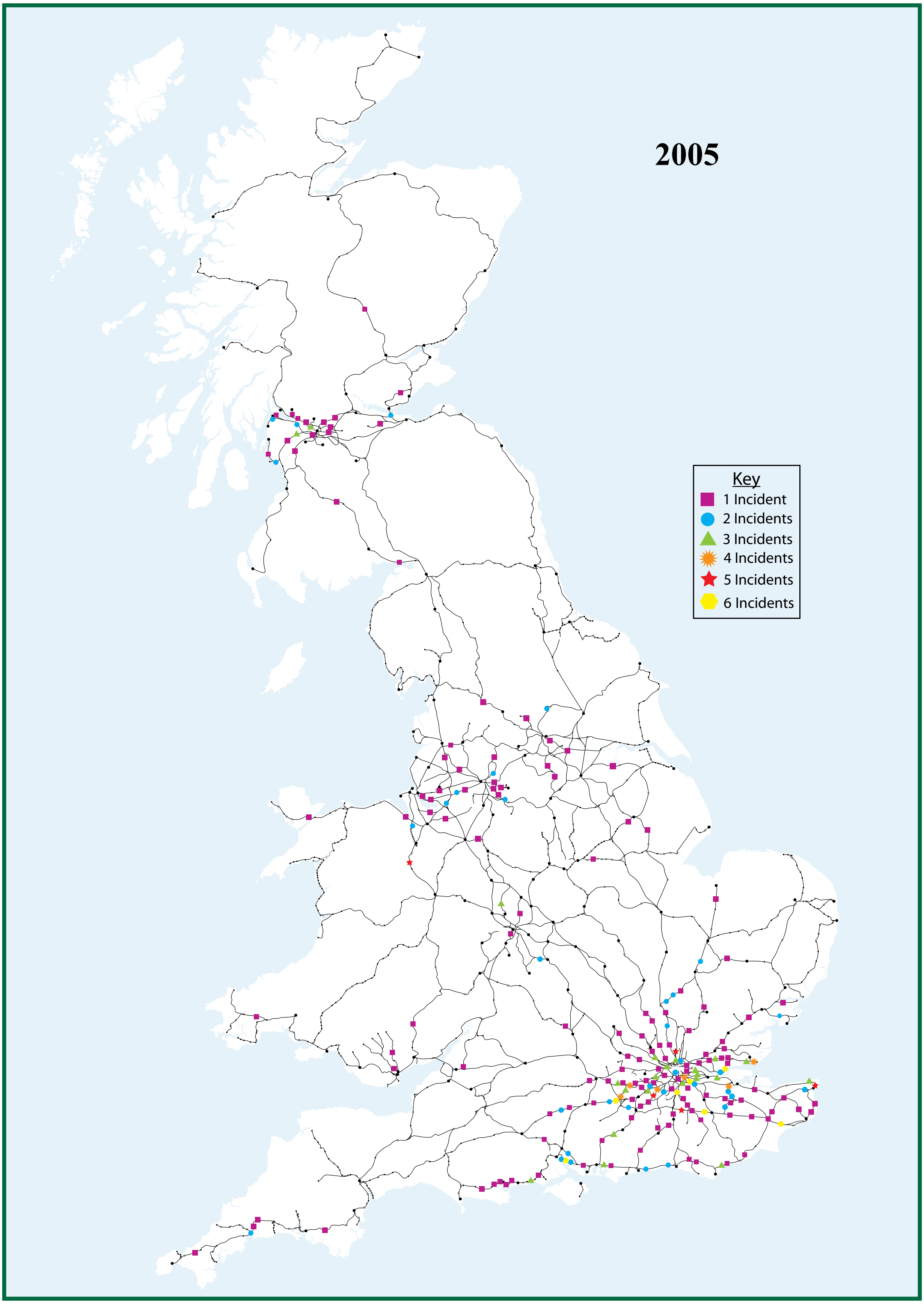


Figure 7b: Distribution of adhesion-related incidents - 2005.

Rolling stock characteristics

71 The performance of each of the fleets of rolling stock during autumn 2005 has been examined to try to establish whether there are any common characteristics that they share that might help to explain the reasons why some fleets were more likely to be involved in adhesion-related incidents than others. Performance between different fleets is not comparable without normalising the data to take account of fleet size or fleet operation. Figure 8 contains two columns, the first ranks the fleets according to the number of low adhesion incidents experienced when normalised by fleet size (no. of incidents/number of units in fleet). The second column ranks the fleets according to the number of low adhesion events experienced when normalised by activity (no. of incidents/annual mileage). The latter analysis was undertaken by Network Rail and First Group. The fleet ranked '1' is that which experienced the highest number of adhesion incidents.

Rank	Normalised by total number of units in fleet	Normalised by annual mileage
1	314*	458*
2	450	314*
3	508+	508+
4	334	320*
5	357+	450
6	375	334
7	444	357+
8	458*	313*
9	320*	375
10	365*	142^

Key
^Fleets equipped with neither sanders nor WSP
**Fleets not equipped with sanders*
+Fleets partially equipped with sanders (for autumn 2005, majority of Class 508 was equipped, majority of Class 357 was not equipped)

Figure 8: Highest occurence of adhesion-related incidents - normalised by fleet size and by annual mileage.

72 *Electric Multiple Units* (EMU) classes account for the top ten places when expressed on an 'incident per fleet size' basis and nine of the top ten places when expressed on an 'incident per miles operated' basis. Eight of the classes appear in the top ten whether normalised by fleet size or mileage. Classes 365 and 444 appear within the top ten only when normalised by fleet size. Classes 142 and 313 appear within the top ten only when normalised by mileage operated. The Class 142 is the only diesel multiple unit (DMU) that appears on either list.

73 There is no single reason that explains the presence of the fleets that occupy the top ten places, but there are reasons why individual classes appear in the top ten and these are explained below.

74 The Class 314 is ranked at or nearly at the top of both lists. The fleet, comprising 16 units, operates local services around Glasgow with frequent station stops. Although fitted with a WSP system, the Class 314 is not equipped with sanders.

75 The Class 458, which appears either 8th or 1st depending on how performance is ranked, is operated almost exclusively over the Waterloo to Reading route which is characterised by frequent station stops. Every adhesion related incident occurred between Virginia Water and Earley, in the more rural section of the route. During autumn 2005, the Class 458 was fitted with a WSP system but not equipped with sanders.

76 The performance of the Class 508 which appears third on each list was variable. Three TOCs operated the Class 508 (and the similar Class 507) during autumn 2005, Merseyrail, Silverlink and South Eastern Trains. The Class 508 units operated by Merseyrail and South Eastern Trains were equipped with a WSP system and sanding, while the Class 508 fleet operated by Silverlink was equipped with a WSP system only.

77 Merseyrail, the dominant operator of the Class 508, experienced no adhesion-related incidents in autumn 2005, while Silverlink experienced a single incident. Fifteen incidents were attributable to South Eastern Trains's fleet of 12 units.

78 South Eastern Trains conducted its own analysis into performance during autumn 2005 and has concluded that the reasons for the poor performance of the Class 508 were:

- The Class 508 fleet operated predominantly in single unit (three car) formations.
- The vehicles were the lightest of South Eastern Trains's fleet.
- It had a 'one-shot' sanding system, which limited the amount of sand that is available to a driver during prolonged slides.
- The WSP system was a 'first generation' device, lacking the sophistication of the systems fitted to units delivered recently. See paragraph 144 for a description of the characteristics of older WSP systems.
- The Class 508 fleet operates over two routes that have traditionally suffered a high number of overrun incidents during low adhesion conditions (Medway Valley and Tonbridge to Redhill). The former route follows the river Medway, which raises the moisture level and it also runs through areas of lush vegetation. The latter route is straight and level but exposed to the elements.

79 The analysis performed by South Eastern Trains demonstrates the need to treat the information in Figure 8 with caution. There are a range of variables that might explain different levels of performance. The most obvious is stopping pattern; the greater the number of station stops, the greater the exposure to a possible overrun. EMUs operate the majority of services around the major cities that stop frequently and would therefore be more exposed to the hazard of overrunning stations. However, suburban routes around cities have relatively low levels of vegetation alongside the line in comparison with rural areas. The fleets that perform much of this suburban work to the south and south east of London (Classes 455, 456, 465 and 466) do not appear in either top ten.

80 One specific issue that the RAIB's investigation sought to address was whether 'modern' trains are more susceptible to adhesion-related incidents than older trains. In attempting to undertake such an analysis, the principal difficulty was in defining what was meant by 'modern' and 'older'. Some modern trains were not equipped with sanders during autumn 2005 (e.g. Classes 357/0 and 458) while some older trains were (e.g. Classes 159 and 323). Age alone is not a basis for comparison when some older units have been retrospectively equipped with modern systems for dealing with low adhesion conditions.

81 However, the opportunity to compare modern and older trains was available in the South East of England where four operators had modernised their fleets in a relatively short period of time. It was therefore possible to compare adhesion performance in the years 2000, 2004 and 2005 to establish whether there were significant differences that might help to establish whether modern rolling stock was more susceptible to adhesion-related incidents.

82 The fleets considered were those that operate the 'main line' services of SWT, Southern Railway (formerly Connex South Central) and South Eastern Trains (formerly Connex South Eastern) and those operating all services of c2c. See Figure 9

Operator	2000 Fleet	2005 Fleet
South West Trains	Class 411, 412, 421, 423	Class 444, 450, 458
Southern (Connex)	Class 411, 421, 423	Class 377
South Eastern Trains (Connex)	Class 411, 421, 423	Class 375*
c2c	Class 310, 312	Class 357

Figure 9: Classes comprising main line fleets of South West Trains, Southern Railway, South Eastern Trains and c2c in 2000 and 2005.

83 Figure 10 shows the number of adhesion-related incidents involving relevant fleets in 2000 and 2005. Although it would have been possible to normalise the figures by the number of units in each fleet, this would have biased good performance towards the 2000 fleet because of the high levels of utilisation achieved with modern rolling stock. Given that the geographical boundaries for the four operators have not changed in the intervening period, the figures simply represent the number of incidents occurring within their operating area for the two years involving the designated rolling stock.

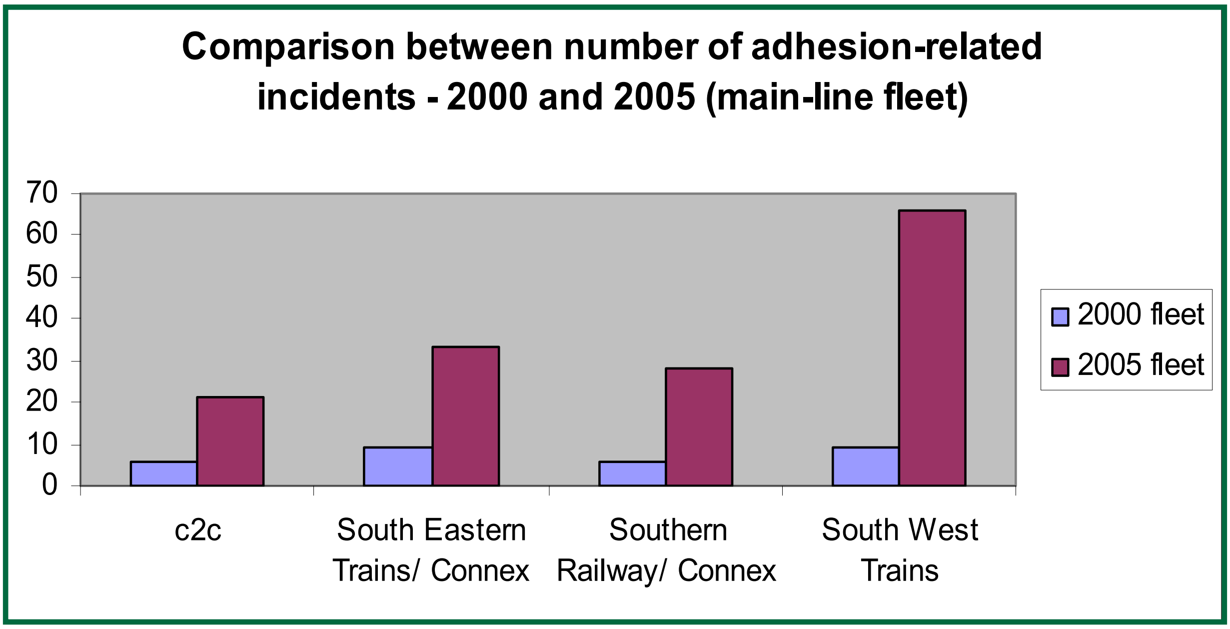


Figure 10: Numbers of adhesion-related incidents affecting main line fleets of four TOCs, 2000 and 2005.

84 A possible explanation of the differences between the two years might be that weather and environmental conditions in the two autumns were not comparable. In order to determine whether this might be the case, a comparison was made between the numbers of adhesion-related incidents in 2000 and 2005 involving the suburban fleets used by South Eastern Trains, Southern Railway and SWT, which did not change significantly in that period. Figure 11 shows that for two of the three operators, there was an improvement in performance between 2000 and 2005, whereas for the third, although there was a deterioration in performance (31% worse), it was not as marked as that experienced by the main line fleet (267% worse). This suggests that any difference in weather and environmental conditions between the two years was not necessarily relevant to performance.

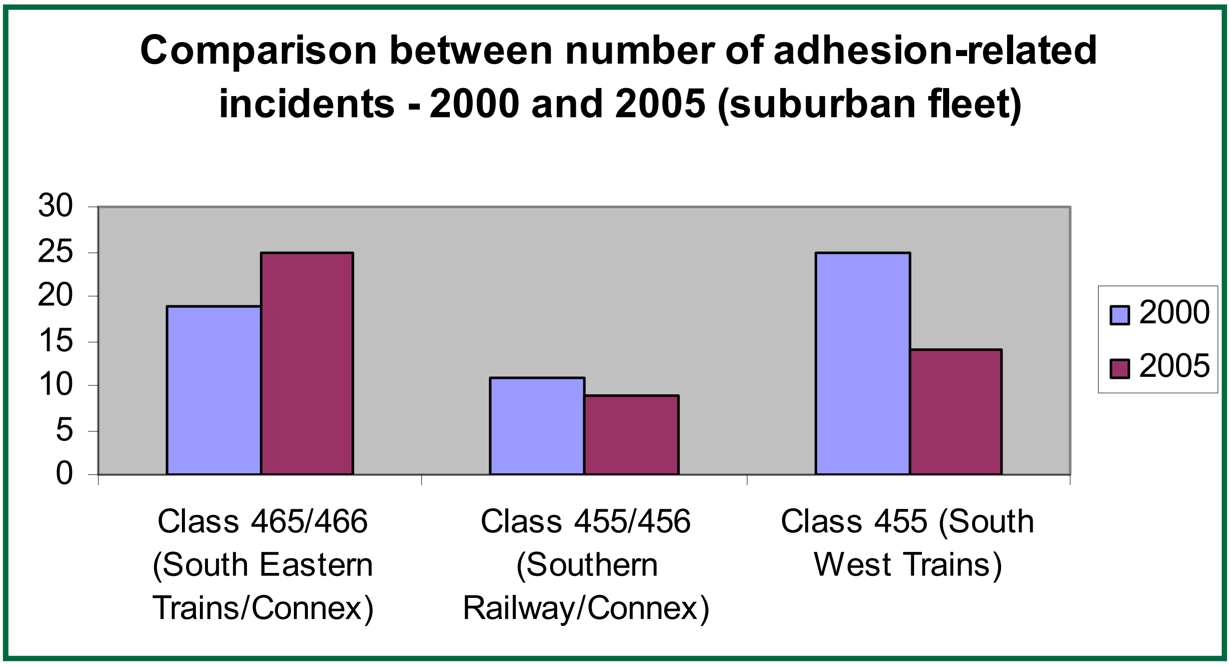
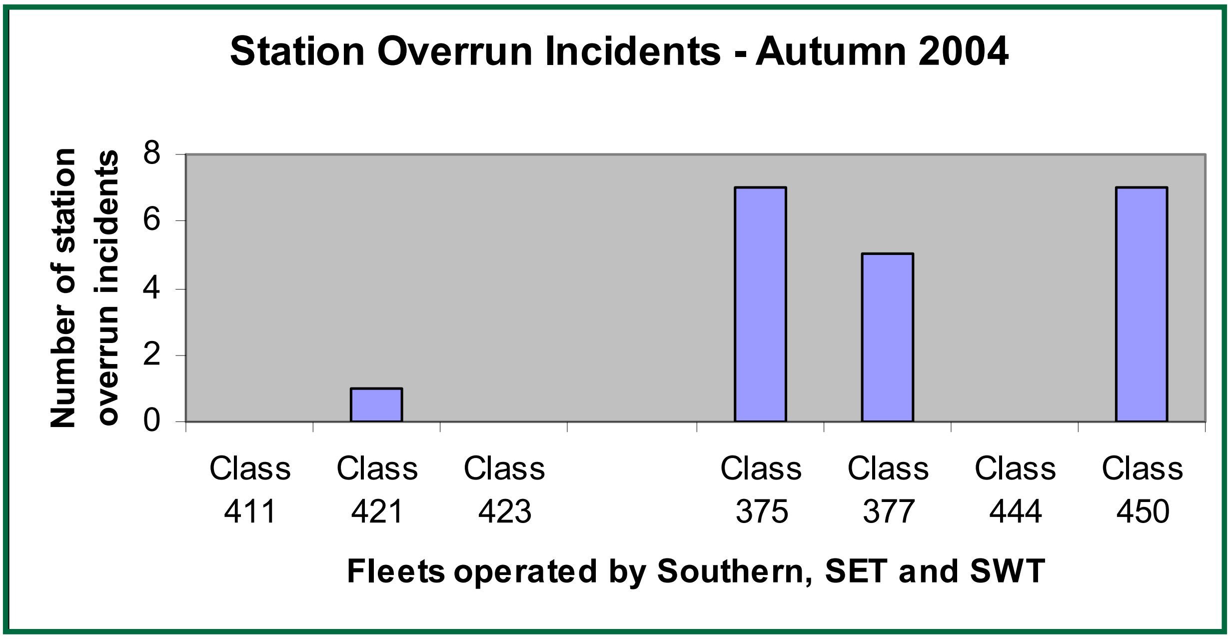


Figure 11: Numbers of adhesion-related incidents affecting suburban fleet of SWT, Southern Railway and South Eastern Trains in 2000 and 2005.

85 One further possible basis for comparing the adhesion-related performance of modern and older rolling stock is to use data from autumn 2004, this being the year when old and new fleets of main line stock used by Southern, South Eastern Trains and SWT were operating alongside each other over the same routes. It has not been possible to obtain exact figures for the amount of old and new stock operated by these three TOCs during autumn 2004 as the proportion of new stock was increasing throughout the period, but it is probable that old stock still accounted for approximately 30%-40% of the main line services operated collectively by the three companies. Figure 12 shows the involvement of each fleet in station overrun incidents during autumn 2004. It indicates that there was a disproportionate involvement of new stock in adhesion-related incidents. Although the Class 444 units operated by SWT appear to run counter to this trend, the fleet was the last to be introduced by SWT and may not have been fully operational throughout autumn 2004.



OLD [Class 411, 421, 423]
NEW [Class 375, 377, 444 and 450]

Figure 12: Occurrence of station overrun incidents during autumn 2004 - comparison of new and old classess.

86 Analysis of figures 9-12 shows that the modern rolling stock operated by South Eastern Trains, Southern and SWT was more susceptible to adhesion-related incidents than the older stock it replaced, despite having sophisticated WSP and sanding systems. However, Figure 13 shows that the number of adhesion-related incidents experienced with the four classes of modern rolling stock increased disproportionately between 2004 and 2005, suggesting that factors additional to those associated with the trains also contributed to the relatively high number of adhesion-related incidents in autumn 2005.

	2004	2005
Class 375	7	33
Class 377	5	28
Class 444	0	13
Class 450	7	46

Figure 13: Comparison between numbers of adhesion-related incidents experienced by Classes 375, 377, 444 and 450 - 2004 and 2005.

87 Reference was made in paragraph 76 to the performance of Classes 507/508, which are operated by three TOCs (in Merseyside, North West London and Kent/Sussex) and experienced different numbers of adhesion-related incidents in autumn 2005. The Desiro family of EMUs have similar characteristics and operates in different parts of the country. The number of adhesion-related events affecting each Desiro fleet is summarised below:

- The Class 444 and 450 units are operated by SWT predominantly over the Wessex Route (Surrey, Hampshire, Dorset and Berkshire). In autumn 2005, there were 45 five car Class 444 units in operation and 109 four car class 450 units in operation. There were 59 adhesion-related incidents affecting these units in autumn 2005.
- The Class 350 unit is operated jointly by Silverlink and Central Trains over the West Coast Main Line. In autumn 2005, there were 30 four car units in operation. There were no adhesion-related incidents affecting these units in autumn 2005.
- The Class 360 units are operated by 'One' (21 four car units) on main line services in Essex and Heathrow Express (5 four car units). There were three adhesion-related incidents affecting these units during autumn 2005 (two affecting units operated by 'One' and one affecting units operated by Heathrow Express).

88 The analysis of the Desiro fleets provides further evidence that it is not rolling stock characteristics alone that determine the number of adhesion-related incidents.

89 Improvements in suspension and bogie performance of modern stock give a better ride for passengers and help to reduce impact on the track when compared with the stock that it replaced. Although the ride quality for passengers on older stock might have been lower and resulted in more wear and tear on the track, it may also have cleaned a greater area of the rail surface than is the case with modern stock.

90 There is a degree of similarity in the ride characteristics of modern freight rolling stock and older passenger rolling stock. The Wessex route suffered 89 adhesion-related station overruns in autumn 2005, but there were none on the section of line between Basingstoke and Totton (west of Southampton) where there is a significant flow of container trains to and from the docks at Southampton and other traffic to and from the Fawley branch. There were adhesion-related incidents immediately to the east of Basingstoke and immediately to the west of Totton. Given the rural nature of the majority of this route, this provides tentative support for the theory that trains with more primitive suspension systems

are effective at cleaning contaminant from the rail head, which may provide a partial explanation as to why the modernisation of the passenger fleets operating in the south east has been accompanied by an increase in adhesion-related incidents.

Summary

91 The analysis contained in paragraphs 60 to 90 has shown that there was a different distribution of events throughout the autumn period for the three years (2000, 2004 and 2005). The distribution of events by length of overrun was similar for each of the three years, although there were detailed differences when analysed by time of day.

92 Geographically, there is a concentration of adhesion-related events in the south east, north west and Scotland but the low number of incidents occurring in the Midlands means that there is no correlation between density of traffic and numbers of incidents.

93 The characteristics of different rolling stock fleets operating over the national network vary. WSP and sanders are systems provided to deal with low adhesion conditions, but they are not available on all fleets. Units not equipped with sanders featured prominently in adhesion-related incidents in autumn 2005, but modern fleets equipped with WSP and sanders also experienced a significant number of incidents.

94 A comparison between the performance of modern stock in the south east during the low adhesion period and the stock that it replaces showed that despite the availability of WSP and sanders, modern trains appeared to be more susceptible to adhesion-related events. However, a review of similar fleets operating in different parts of the country showed that performance within fleets also varied, indicating that the characteristics of the rolling stock alone do not account for the high numbers of adhesion-related events experienced by some fleets.

95 The characteristics and distribution of adhesion-related incidents in autumn 2005 were affected by a complex range of factors. The analysis contained in the remainder of this report will show that adhesion performance in 2005 was affected by:

- infrastructure factors, including the identification of sites for rail head treatment and differences in practice with regard to the treatment given;
- rolling stock factors, including the availability and characteristics of WSP and sanding systems and the standards that help to shape those characteristics;
- operational and management factors, including driving policy and practice, briefing of drivers and the procurement and approvals processes for new rolling stock.

Assessment of causal and contributory factors

Infrastructure Factors

Introduction

96 This section contains an analysis of the causal and contributory factors for adhesion-related events associated with the infrastructure. It considers:

- the process used by Network Rail for determining which parts of the railway are subject to railhead treatment;
- different methods for treating the rail head to counter the effects of low adhesion;
- rail head treatment policy for autumn 2005;
- the relationship between different types of rail head treatment and adhesion incident occurrence rates in 2004 and 2005;
- short-term prediction of adhesion problems;
- delivery of rail head treatment;
- other infrastructure issues.

Process for determining railhead treatment

97 The process used by Network Rail to determine which parts of the network receive railhead treatment has been described in paragraph 34. The approach used for autumn 2005 focused primarily on historical performance and feedback from TOCs and infrastructure maintenance staff. It overlooked the fact that low adhesion conditions can remain undetected until a train is required to accelerate or stop and that approaches to junctions and some level crossings where trains do not normally stop do not have the benefit of railhead conditioning.

98 During 2006, Network Rail's Wessex route in conjunction with SWT developed and implemented a risk-based approach to identifying areas of low adhesion that takes account of the potential of low adhesion incidents to cause disproportionate harm at key locations such as junctions and level crossings. This facilitates the identification of potential low adhesion locations that require special attention.

Methods of rail head treatment

99 Paragraph 36 describes the methods employed by Network Rail to treat the rail head. Network Rail and its predecessor organisations performing the role of Infrastructure Manager for the national network have experimented with novel methods of rail head treatment to improve adhesion including surface scrubbing and laser cleaning. However, the methods have proved to be impractical (lasers only work at very low speed and brushes wear out rapidly).

100 The techniques that have been used most widely and consistently are water jetting and the application of Sandite. There is an important distinction between the effect of water jetting and Sandite. The purpose of water jetting is to clean the rail head. The purpose of applying Sandite is to enhance adhesion levels at the wheel/rail interface but there is a risk that if it not applied properly, it can act as a contaminant and prevent trains from operating track circuits.

101 Research and testing to determine the best method for treating the rail head has been carried out over a number of years. Network Rail undertook testing on the Ministry of Defence railway at Bicester in spring 2003 to try to identify the optimum method of treating the rail head. The results of this and subsequent tests are included within the AWG report into low adhesion incidents in autumn 2005. The report states that the tests demonstrated:

- water jetting was effective for cleaning the rail head at the low speeds employed in the tests;
- sandite improves rail head adhesion and is not detrimental to train detection if it is properly spread over the surface of the rail by the MPV.

102 During autumn 2003 Network Rail measured the effectiveness of water jetting and Sandite and concluded that both methods were effective in achieving their purpose 'to some degree'. In spring 2004, trials were undertaken at Bury in order to test the effectiveness of water jetting at 40 mph (65 km/h) (speeds that were not achievable on the MOD site at Bicester). The trials at Bury were also used to test different nozzle configurations for the water jet. The results from the Bury trials showed that:

- water jetting on rail treated with an unmodified nozzle at a speed of 30 mph (50 km/h) gave an improvement of 40% in braking performance when compared with braking on untreated rail;
- the modification to the water jet nozzle gave an improvement in braking performance of 70% at a speed of 30 mph (50 km/h) when compared with braking on untreated rail;
- if MPV speed was increased to 40 mph (65 km/h), the improvement in braking performance when compared with braking on untreated rail was 45% with the modified nozzle;
- the optimum application speed for Sandite was 30 mph (50 km/h) and that it was an effective way of improving braking performance in low adhesion conditions.

103 Taking the effectiveness of water jetting into account and also considering that the slower speed at which Sandite had to be applied represented a disadvantage in terms of finding *train paths* for the MPV, Network Rail concluded that water jetting at 40 mph (65 km/h) was the most effective form of rail head treatment for all but severe low adhesion conditions. On days when low adhesion conditions were expected to be severe, Sandite would be required in addition to water jetting.

Railhead treatment policy for autumn 2005

104 Although Network Rail had the results from the trials at Bury available before autumn 2005 there was no central direction on which methods of rail head treatment should be applied nationally. Network Rail routes made their own decisions about the rail head treatment that would be applied. In 2004, all routes had employed water jetting and Sandite. In 2005, the option was available to employ water jetting alone. The treatment applied to each route is summarised in Figure 14.

Route	Rail head treatment	Comments
Anglia	Water jet	
Chiltern	Water jet/Sandite	The Chiltern TOC treats the infrastructure south of Bicester using its own equipment
Kent	Water jet and water jet/Sandite	Water jet only to mid-November, water jet & Sandite thereafter
London North Eastern	Water jet/Sandite	GN north of Peterborough, Hertfordshire Loop and Cambs Branch daytime water jet only
London North Western	Water jet	Watford DC and Merseyrail water jet/Sandite
Scotland	Water jet and water jet/Sandite	Water jet only to end October, water jet/Sandite thereafter
Sussex	Water jet/Sandite	
Wessex	Water jet	
Western	Water jet and water jet/Sandite	Water jet & Sandite west of Newton Abbot and on main line in Cornwall from 9 November

Figure 14: Methods of rail head treatment during autumn 2005.

<u>*Relationship between railhead treatment and incident occurrence rate*</u>

105 Figure 15 shows the proportion of adhesion-related incidents attributable to the eight routes plus Chiltern in 2004 and 2005.

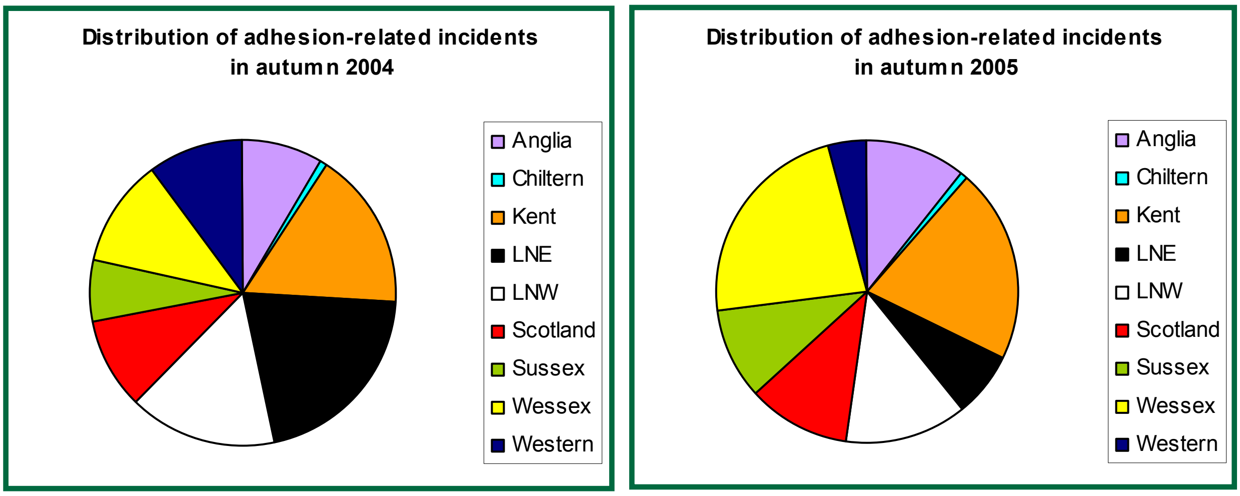


Figure 15: Distribution of adhesion-related incidents in autumn 2004 and autumn 2005.

106 Figure 15 presents a mixed picture. Wessex, a route that changed from water jetting and Sandite in 2004 to water jetting only in 2005, was responsible for a higher proportion of the total number of adhesion-related incidents in 2005 than 2004. However, Sussex, which used water jetting and Sandite both years, also saw an increase in its proportion of adhesion-related events. Conversely LNW, which also moved from water jetting and Sandite in 2004 to predominantly water jetting only in 2005 saw a decrease in its proportion of adhesion-related incidents over the two years. The most dramatic decrease in occurrence rate occurred on LNE route, where there was a reduction in the use of water jetting and Sandite in 2005, but not eradication.

107 In Kent, Scotland and Western, rail head treatment for all or part of the route changed from water jetting only to water jetting and Sandite during the autumn period and this further complicates the analysis. In these three cases, the type of treatment changed because the principal TOC in that area had asked for Sandite to be applied.

108 In Scotland, the change coincided with a reduction in station overruns although this could have been attributable to the fact that in Scotland, autumn tends to start and finish earlier than in the southern half of Britain, and the second half of autumn normally features fewer adhesion-related incidents than the first. However, on the Edinburgh-Glasgow route, it was not possible to use Sandite in the second half of autumn because of lack of train paths. Although there was a reduction in the number of incidents on this route after the reversion to the use of Sandite elsewhere, the reduction was not as dramatic as the reduction on the routes where Sandite application was reinstated. This supports the outcome of the trials conducted by Network Rail (paragraphs 101 and 102) with regard to the effectiveness of Sandite.

109 Overall, because of the contradictory nature of the evidence, it is not possible to be certain about the circumstances under which water jetting alone or water jetting and Sandite in combination is the optimum railhead treatment policy. As the numbers of 'failure to operate track circuit' incidents remained fairly constant between 2004 and 2005, no immediate benefit for the greater use of water jetting can be claimed in this respect. Sandite improves adhesion but the lower operating speed for MPVs applying Sandite in autumn 2005 meant that the extent of railhead treatment over the network would have been lower than was achieved by employing a combination of the two methods.

110 In June 2006, further rail head treatment tests were undertaken at Bury. Network Rail reported that the findings from the tests showed that the effectiveness of water jetting with Sandite was the same for a Sandite flow rate of 4 litres/minute at 30 mph (50 km/h) and 2 litres/minute at 40 mph (65 km/h). Network Rail considered that the trials had shown that Sandite could now be laid effectively at 40mph (65 km/h) providing that it was laid at the lower flow rate. Network Rail also concluded that water jetting and Sandite is a more effective method of rail head treatment than water jetting alone. For autumn 2006, Sandite has been applied at speeds of 40 mph (65 km/h) at the lower flow rate of 2 litres/minute. A small number of MPV circuits employed water jetting alone, in agreement with the relevant TOCs.

111 The effectiveness of Sandite diminishes over time. The speed with which this takes place is directly related to usage, i.e. the number of wheels that pass over the treated rail. Network Rail's own assessment is that Sandite is only effective for the passage of 100 axles (which would equate to three hours for routes over which two four-car trains per hour are operated). Sandite can also be washed off by rain. Water jetting was claimed by Network Rail to be effective for up to eight hours. Although no evidence has been seen to support these assertions, it is likely that the rate at which the effectiveness of Sandite diminishes will be affected by the intensity of train service operating over the route.

112 A number of changes have been made to the rail head treatment regime in the last few years and, as explained in paragraph 110, further changes were made for autumn 2006. While each of the trials helps to advance knowledge on rail head treatment, this can only be validated by operational experience over more than one autumn. Network Rail is committed to the continuation of trials and consultation with TOCs in order to inform future policy decisions on rail head treatment. Changes in rail head treatment technology are likely to bring with them the need for further trials. The optimum method for treating the rail head will change over time. It is important that the rail head treatment strategy for each autumn is based on sound evidence that it constitutes the optimum approach. The outcome from trials is a significant input to that strategy as is experience from previous autumns.

<u>*Short-term prediction of adhesion problems*</u>

113 Network Rail establishes its rail head treatment policy well in advance of the autumn period, but this is subject to short-term modification depending on forecasts of conditions that could result in poor rail head adhesion. The *ADAS classification system* is used to predict likely adhesion conditions on each specific day in the autumn, a process which starts with a five day forecast and is then refined over the next five days. During autumn 2005 the accuracy of the ADAS system was inconsistent in its prediction of the days when the highest number of adhesion-related incidents would occur. Figure 16 shows a comparison between the worst 5 days for autumn predicted by ADAS and the worst 5 days as actually experienced in autumn 2005:

	Good correlation between ADAS predicted ranking and actual ranking		**Poor correlation between ADAS predicted ranking and actual ranking**	
	ADAS Prediction *	**Actual ***	**ADAS Prediction***	**Actual ***
24 October			5	26
25 October			3	18
28 October			20	4
3 November	1	2		
8 November	4	6		
11 November	2	5		
25 November			14	1
16 December			29	3

* 'ADAS Prediction' refers to the ranking of that day in relation to the 85 days of the autumn period where '1' represents the worst predicted day for adhesion related incidents. 'Actual' refers to the actual ranking of that day in relation to the 85 days of the autumn period where '1' represents the worst actual day for adhesion-related incidents

Figure 16: Comparisons of ADAS predictions with actual experience.

114 The good standard of predictions for 3, 8 and 11 November shows that the ADAS system is capable of producing useful data and a forewarning to the industry of difficult days. The value of good predictions is that they enable Network Rail to take additional measures to cope with severe conditions, as described in paragraph 37. The poor predictions for 28 October, 25 November and 16 December show that there is scope for improvement. There should be ample evidence from last autumn to establish why high numbers of adhesion-related incidents occurred on days when the forecast was relatively benign.

115 In autumn 2005, the ADAS system produced area-specific forecasts for 16 areas across the network, grading the risk as low, medium, high or extreme. This resulted in the application of the forecast to relatively large areas when, conversely, the phenomenon of low adhesion can be localised:

- On 28 October 2005, there were 12 adhesion-related incidents in Scotland, including two within a few minutes of each other at the same location (but involving trains running in opposite directions). The ADAS prediction for this part of the network on 28 October was medium risk.

- Reference was made in the Part 1 report on the SPAD at Esher to the occurrence of 15 other adhesion-related incidents on 25 November 2005 within a 25 mile radius of Esher between 06:00 hrs and 09:00 hrs, with two other incidents occurring within a five mile radius between 06:15 hrs and 07:05 hrs. The ADAS prediction for this part of the network on 25 November was medium risk.
- On 8 December 2005, two adhesion related station overruns affected successive stopping trains at Hook and Fleet within 15 minutes of each other, the stations being located six miles apart. The ADAS prediction for this part of the network on 8 December was low risk.
- On 12 December 2005, three adhesion-related station overruns occurred on the Cobham line at Claygate, Cobham and Effingham Junction within the space of two hours (20:50 hrs – 22:55 hrs), over six route miles of railway. The ADAS prediction for this part of the network on 12 December was low risk.
- On 16 December 2005, the Hertford loop was closed at the end of the morning peak following overruns at the adjacent stations of Grange Park (07:14 hrs) and Winchmore Hill (07:45 hrs and 08:35 hrs) and numerous reports from drivers of adhesion difficulties. It was afternoon before the route could be reopened. The ADAS prediction for this part of the network on 16 December was medium risk.

116 The examples contained in paragraph 115 show that poor adhesion conditions can be prevalent in a localised area for a relatively short period of time. London Underground and Metronet Rail (BCV) have, since 2001, been operating a system on the Central Line that employs a number of sensors to detect changes in humidity at different sites. The system was needed because Central Line trains normally operate in *automatic train operation (ATO) mode* with the braking regime configured for normal adhesion conditions. If low adhesion conditions are present manual driving is employed and it is thus important to have an accurate prediction of adhesion conditions. Using measurements of moisture locally in conjunction with predictions regarding leaf-fall and train speeds in the open sections of the Central Line, the system provides a real time risk ranking, which can be used by Line Controllers to decide whether trains can be allowed to continue to operate in ATO. The system has been refined and consideration is now being given to its extension to other London Underground lines.

117 The AWG has embarked on developing an Adhesion Management System for the national railway network based on the system in place on the Central Line, with the objective of achieving timely and accurate identification and reporting of low adhesion conditions on the main line network. Development testing of the system is taking place on the Chiltern Lines during autumn 2006.

<u>*Delivery of rail head treatment*</u>

118 The report prepared by AWG on low adhesion events in autumn 2005 makes reference to difficulties in determining an overall picture of the number of occasions when there was a failure to deliver planned treatment of the network by MPVs. As an example (which is not necessarily representative of the nationwide picture), the performance of MPVs in Kent in autumn 2005 showed that a number of factors affected the delivery of railhead treatment. Network Rail's Kent route has five MPV circuits, which are operated twice a day. Two further MPVs are held in reserve for rapid response purposes. In the period between 3 October and 7 December 2005:

- There were only 3 occasions when a complete circuit did not operate because of an MPV not being available, representing a MPV availability rate of 99.5%.

- On 17 occasions, one circuit was cancelled by Network Rail. This, together with the three circuits affected by non-availability of MPVs, was equivalent to 3% of all planned circuits being cancelled.
- On 65 occasions, parts of one circuit were not delivered for various reasons, mainly because of mechanical problems on the MPV or because it ran out of water.
- The overall success rate for the MPVs in Kent in achieving their complete circuits as scheduled was 87%.

119 Network Rail, while endeavouring to operate all rail head treatment trains, also advises TOCs if it has not been possible to treat a particular part of the network. This information is cascaded to drivers via *late notice arrangements*.

Other infrastructure issues

120 The suspension system and ride characteristics of modern rolling stock are superior to older stock (paragraph 90). One consequence of this is that modern stock only makes contact with (and cleans) a narrow strip of the rail head. The rail head in areas where only modern rolling stock operates shows a narrow wheel contact path, i.e. a consistent point of contact. All the forces imparted from the train in normal running are applied to this narrow contact strip. There is no cleaning of the remainder of the rail surface by the passing of trains. However, there is no reason why train wheels should follow a different path in traction, coasting and braking, which means that the narrow contact strip is of no relevance to the causes of incidents in low adhesion conditions.

121 The braking rate achieved by trains using the national network is dependent on the level of adhesion available at the interface between wheel and rail. Modern trains are required by RGS to brake at a rate of at least $0.9m/s^2$ in full service (step 3) braking (higher values apply for some fleets). Braking in steps 1 and 2 results in decelerations at $0.3m/s^2$ and $0.6m/s^2$ respectively. A braking rate of $0.9m/s^2$ will be achievable only if an adhesion level of approximately 0.09 (paragraph 9) is available at the wheel/rail interface. Wheelslide occurs when the required braking rate of the train, as requested by the driver in selecting brake step 1, 2 or 3, cannot be matched by the level of adhesion available at the wheel/rail interface. Some trains are equipped with *stepless brake controllers* which permit a greater degree of control over the brake rate demanded, but the principle of the braking rate demanded being affected by the level of adhesion available remains the same.

122 During autumn, the level of adhesion may drop to below 0.03 as a result of the presence of rail head contamination. If adhesion levels drop below 0.03, a train will experience wheelslide as soon as brake step 1 is selected by the driver.

123 It is possible that sustained lengths of low adhesion are a more common phenomenon now than was the case fifteen years ago. In the early 1990s, a *tribometer train* ran over the national network to establish the prevailing levels of adhesion. At that time, average adhesion levels of 0.04 over significant distances were found, but the train took measurements over a limited part of the network. In the SPADs at Esher and Lewes, and in the case studies included at Figure 3, the average levels of adhesion available were below 0.02 in some areas. Data gathered in the 1990s by the tribometer train is still used to test and optimise WSP systems.

124 Reference was made in paragraph 32 to the problems associated with severe low adhesion conditions and the invisible contamination that was the cause of the SPAD at Esher. This phenomenon is not well understood currently. In particular, there is a need to understand what form this contamination takes, how it attaches itself to the rail head and the circumstances under which it becomes a particular threat to the operation of the railway. Only with this understanding can appropriate strategies for dealing with the causes of severe low adhesion be developed.

Infrastructure factors – key issues

125 The analysis contained in paragraphs 97 - 124 has shown that the following infrastructure factors are relevant to the high number of adhesion-related events experienced during autumn 2005:

- The approach to the identification of high-risk low adhesion areas on the national rail network was biased towards historical data and recent performance rather than risk arising from the configuration of the infrastructure (e.g. junctions and level crossings) (paragraph 97).
- Uncertainty over the optimum method for treating the rail head resulted in different methods of treatment being employed across the network. There is contradictory evidence from autumn 2005 with regard to the optimum strategy for railhead treatment (paragraph 109) and further changes made for autumn 2006 need to be validated (paragraph 112).
- There was variable performance in the prediction of low adhesion conditions. The overall accuracy of rail head condition prediction using the ADAS system throughout autumn 2005 was unreliable (paragraphs 113-115).
- Significant lengths of low adhesion were experienced on a number of occasions during autumn 2005 and it is possible that they are now occurring more frequently than has been previously thought to be the case (paragraph 123).
- There is a lack of understanding regarding the mechanisms that create severe low adhesion conditions including invisible contamination and methods for treating it (paragraph 124).

Rolling Stock Factors

Introduction

126 It was shown in paragraph 80 - 86 and accompanying figures that modern rolling stock in the south east had featured more prominently in adhesion-related incidents in autumn 2004 than older stock. The review of infrastructure issues has shown that variability in the way that the infrastructure was treated may have had an impact on performance but there are issues associated with rolling stock that also need to be considered. Most modern fleets are equipped with software driven WSP systems and sanding, which were not installed on the fleets they replaced. These systems should give modern rolling stock an advantage in stopping in low adhesion conditions. In seeking to understand why modern rolling stock has experienced a high number of adhesion-related incidents and what can be done to improve performance, the following areas have been considered:

- the requirements of RGS and TSI;
- technical characteristics of modern trains, particularly WSP, sanding and braking;
- testing and validation of WSP systems;
- alternative methods for stopping trains in low adhesion conditions.

Standards (Railway Group Standards (RGS) and Technical Specifications for Interoperability (TSI))

127 RGS have traditionally provided a framework to govern the specification, design and operation of infrastructure and rolling stock on the national railway network. However RGS have been or will progressively be superseded by TSIs. TSIs are the consequence of the European Economic Community's (EEC) wish to promote the interoperability of rail services throughout Europe. To implement this aim, the EEC published Interoperability Directives in 1996 for high speed lines and in 2001 for other lines that fall within the scope of the Trans European Network (TEN). They set out a number of 'essential requirements' to be met for interoperability, including safety requirements for products and subsystems (trains, signalling, infrastructure, etc).

128 TSIs define the specifications to satisfy these essential requirements and are also divided into two groups, high speed TSIs covering the high speed lines (Channel Tunnel Rail Link, East Coast Main Line, West Coast Main Line and Great Western Main Line in Britain) and conventional TSIs covering the TEN lines.

129 The high-speed TSIs are already in force. The implementation dates for the conventional TSIs vary. The Control Command and Signalling Conventional TSI is published and in force. The conventional TSIs covering freight wagons will come into force shortly but those for locomotives, traction units and passenger carriages will not be in force until 2010 at the earliest.

130 For multiple units, the high-speed TSIs covers rolling stock designed to operate at speeds above 190 km/h (approximately 120mph). This means that only 4% of the multiple units operating in this country are covered by existing TSIs. The conventional TSI for rolling stock is at an early stage of drafting and the requirements of the rolling stock RGS will therefore remain relevant for some time to come.

131 There are a limited number of requirements in RGS on performance of rolling stock under low adhesion conditions. GM/RT2044, 'Braking System Requirements and Performance for Multiple Units' mandates the provision of WSP systems on new disc braked rolling stock and states:

> 'If disc brakes are fitted to the vehicle, a WSP system shall be fitted that ensures that the braking force is controlled, where applicable on a per axis basis, to minimise the extension of stopping distance due to low adhesion.'

132 GM/RT2045, 'Braking Principles for Rail Vehicles' defines braking performance of trains generally, but states:

> 'The braking performance defined in these documents (which include GM/RT2044) relies on the normal level of adhesion being available that is necessary to sustain the brake retarding force demanded. It is accepted that in conditions of low wheel/rail adhesion the friction force that can be maintained at the wheel/rail interface is reduced and other measures to achieve the required stopping distance are necessary such as reduction in speed, railhead surface conditioning or a means of braking that does not rely on the wheel/rail adhesion.'

133 GM/RT2045 lays down requirements for maximum air consumption by WSP to ensure that the braking system does not run out of air. However, there are no quantified criteria for acceptable stopping distances under low adhesion conditions mandated in any RGS. A draft of the revised high speed TSI for rolling stock includes criteria for maximum stopping distances under low adhesion conditions. As currently drafted, it requires specified braking rates to be achieved at defined speeds, irrespective of available adhesion. The implication is that trains must 'artificially' create any shortfall between the required braking rate and the level of adhesion available, using other means such as WSP systems and sanding to do so.

134 GM/RT2461, 'Sanding Equipment Fitted to Multiple Units and On-Track Machines' mandates the fitting of sanders to all new multiple units of previous uncertified design with a Certificate of Conformance for Vehicle Design signed on or after 4 December 2003. It lays down that sanders must:

- In braking mode, as a minimum, discharge sand during full service and emergency brake applications when the presence of low adhesion is automatically detected.
- Operate when WSP indicates wheel speed at 95% or less than train speed.
- Deliver sand from the leading vehicle only at a location forward of the third axle in direction of travel and there must be at least six axles behind the laying position of the sand.
- Achieve a maximum sanding density of 7.5 grams/metre on the rear most two axles of the train. Guidance is also included that indicates this is equivalent to a maximum dispensing rate of 2kg/minute per rail. In order to convert the sanding density to a sanding rate, a dispensing speed of 10 mph (16 km/h) has been assumed. Thus trains running at 10 mph will lay sand at a density of 7.5 grams/metre if the sanding rate is set at 2kg/minute.

135 The purpose of these requirements is to provide minimum standards for configuration of sanding equipment. They have the effect of limiting the amount of sand that can be dispensed. The requirement for six axles behind the point at which sand is delivered is included to ensure that sand is distributed along the surface of the rail, but also has the effect of preventing the single coach Class 153 units and two axles per vehicle Classes 142-144 units from being equipped with sanders.

136 The restrictions applied in RGS GM/RT 2461 are based on concern that too much sand applied at low speed might result in trains being unable to operate track circuits due to sand acting as an electrical insulator between the wheel and the rail. Track circuits are used, inter alia, to control the aspects displayed by colour light signals. If a stopped train failed to operate a track circuit, it is possible that a signal located immediately behind it could, instead of displaying a red aspect, display a yellow or green aspect.

137 More sophisticated systems are available that link sanding rate to train speed. For these systems, derogation from the requirements of GM/RT2461 has been granted and a higher maximum dispensing rate of 4kg/min is permitted with safeguards in the form of low speed cut-off to ensure that sanding at this rate does not take place when the train is travelling at low speed.

Standards – key issues

138 The review of the requirements of RGS and TSI in paragraphs 127 to 136 has shown that:

- there are no requirements within RGS on maximum braking distances under low adhesion conditions (paragraph 133);
- some units are specifically excluded from being fitted with sanders by RGS (paragraph 135).

Technical characteristics of modern trains (WSP, braking, sanding)

Wheelslide Prevention (WSP) Systems

139 This section addresses WSP systems, looking specifically at how WSP systems work and their characteristics.

140 Around 90% of vehicles operating within passenger multiple units on the national railway network are equipped with a WSP system to control braking on a sliding train. The primary function of the WSP system is to limit the extent of wheelslide in order that effective use is made of the available adhesion on the rail head. A further function of the WSP is to prevent wheels locking up and the consequent damage to the wheel tread. The system works by detecting wheelslide and then regulating the rotational speed of the wheels by means of the controlled release and re-application of the brakes. On trains not fitted with WSP systems drivers are instructed to release and apply brakes when experiencing adhesion difficulties in order to find a braking rate that the available adhesion will support.

141 The controlled slip achieved by a WSP system also facilitates the conditioning of the rail head by the wheels. Conditioning can be beneficial because it improves adhesion for following wheels on the same train, although the effectiveness of conditioning is itself influenced by the level of adhesion available (the lower the level of adhesion, the lower will be the benefit from conditioning). Conditioning is also influenced by train length. There is evidence to suggest that the longer the train, the greater the benefit from conditioning., Analysis of data from the incidents at Esher and Lewes (see the part 1 and 2 reports) showed that there is some limited benefit to be obtained from conditioning even with short (four coach) trains (paragraph 66).

142 The process of applying and releasing brakes is achieved pneumatically, which limits the speed and sensitivity with which the braking system can respond to changes in demand because of the pneumatic time constants of the braking system and factors such as wheel inertia which also influences speed of response.

143 WSP systems have been available for a number of years with the result that there are differences in the level of sophistication offered by the system, depending on its age.

144 Information provided by AEA Technology and Interfleet explains the difference between older and more modern WSP systems. Earlier WSP systems modulated the brake cylinder pressure by energising and de-energising a ‘blowdown valve’, which had a single port. This meant that brake cylinder pressure was either at maximum or heading to zero. Only through rapid operation and chokes in the port could intermediate pressure be achieved, allowing some primitive modulation of brake pressure. Later trains have what are termed ‘two stage valves’. Two solenoid valves are controlled individually by the WSP electronics such that with both de-energised, air can pass freely to the brake cylinder but by selective energisation of the two valves, the pressure in the brake cylinder can be vented and/or held at an intermediate pressure. Thus the braking force of an individual wheelset can be more accurately regulated to the prevailing adhesion. In addition, modern WSP systems can be adjusted to enable a finer level of control to be achieved.

145 A simplified overview of the operating logic of a WSP system during train braking is provided at Figure 17.

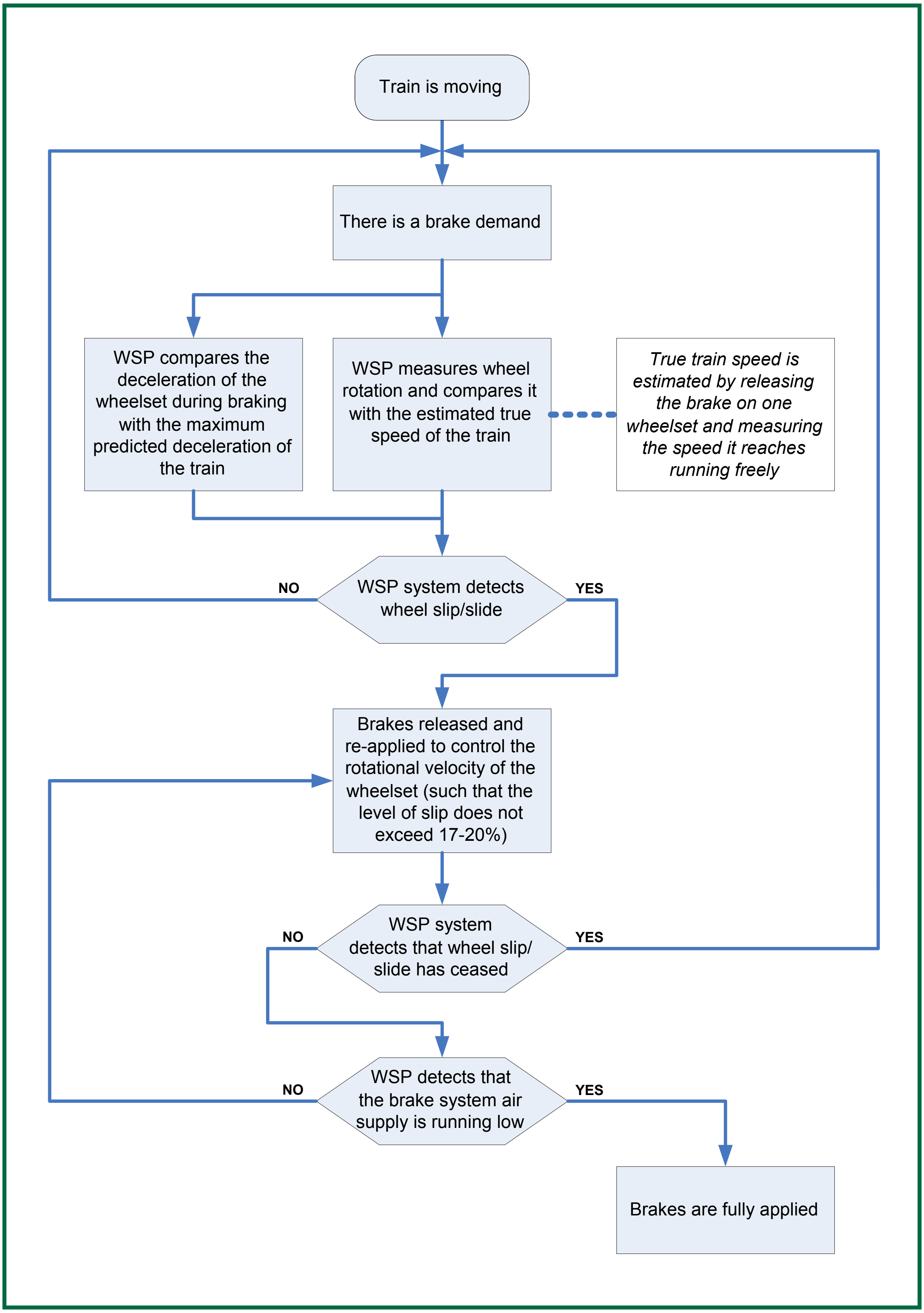


Figure 17: A simplified overview of the logic of a typical modern WSP system when operating during train braking.

146 WSP systems limit the extent to which wheels are allowed to rotate below the real speed of the train. On rolling stock operating over the national rail network, the extent of slip permitted by the WSP system is limited to 17%-20%. A report commissioned by RSSB and prepared by AEA Technology (made available to the RAIB in draft form during the preparation of this investigation report) describes why this level of slip is used on rolling stock operating on the national rail network. It identifies two factors:

- The peak of adhesion occurs at around 1% slip, after which the available adhesion falls away. The control system for WSP requires a linear response to control actions. A slip level in the region of 15%-20% coincides with a linear negative slope that the control system designer can utilise.
- Historically, the testing of WSP systems was undertaken on test tracks with the rails treated with a detergent mixture. This approach resulted in the creation of levels of adhesion at the wheel/rail interface of about 0.06 (see paragraph 9). The best WSP performance at this level of adhesion has been achieved with a slip parameter of 15%-20%, although it may not be optimum for lower levels of adhesion. However, given that trains will encounter variable levels of adhesion, it may not be possible to optimise WSP performance for all conditions encountered.

147 A key issue is whether the slip rate of 17-20% is an appropriate level for meeting the objectives of avoiding damage to wheels and minimising extension of stopping distances. There appears to be no question that it contributes towards the objective of avoiding damage to wheels. TOCs with modern rolling stock equipped with WSP systems report a dramatic reduction in the occurrence of wheel flats, a problem particularly associated with older rolling stock not equipped with WSP. However, the investigation has considered whether there may be an alternative control strategy that would deliver improved stopping distances.

148 There is data available from research in this area[6] Based on information contained within this reference, the advantages and disadvantages of configuring the WSP to control wheel speed to different levels of slip are summarised in Figure 18.

[6] AEA Technology, 'Train Control System Influence on Adhesion Performance', Issue 1, September 2006, Ref AEAT/RAIL/LRIS/LD82057/RP02 Issue 1. This is the most recent research but it also references other work undertaken in this area.

Level of Slip	Designation	Advantage	Disadvantage	Comment
Around 5%	'micro slip'	• Maximises use of the available adhesion	• Degree of control difficult to achieve with pneumatic brake systems because of speed of actuation	May be compatible with hydraulic braking systems
17-20% (currently employed)	'macro slip'	• This degree of control can be achieved with a high degree of reliability while making reasonable use of the available adhesion • Generates sufficient heat/friction to condition the rail head. • Wheel damage will be avoided	• Not as efficient as 'micro slip' in exploiting available adhesion. • Rail head conditioning may not be maximised	This level of slip is currently provided in the WSP systems provided on rolling stock operating over the mainline network
60%+	'deep slip'	• Can maximise benefit of rail head conditioning. • Under certain circumstances the formation of wheel flats can provide further retardation to the train. • Provides shortest stopping distance once better adhesion is encountered	• Inefficient utilisation of the available adhesion • Railhead conditioning dependent on there being sufficient adhesion to generate energy at wheel/rail interface. • Wheel damage is likely to occur.	The additional benefits of rail head conditioning have yet to be measured.

Figure 18: Summary of advantages and disadvantages of different WSP control strategies.

149 Figure 18 shows that there are some significant difficulties with brake control strategies that are different from those currently employed on modern rolling stock (17-20% slip). The ability to improve on stopping distances relates to the brake demand, vehicle dynamic properties and the available adhesion level as well as the level of slip. In a section of line where low adhesion is present the actual level of adhesion throughout the affected section is likely to vary (i.e. there will be peaks and troughs). If the WSP is operating at a reduced level of slip it is able to take more advantage of the available adhesion (i.e. it is working at a value nearer to the peak of adhesion and thus the value of utilisation is effectively higher). Provided there is sufficient brake effort available, the train will stop in a shorter distance.

150 Conversely, it is also possible that the stopping distance of a train in severe low adhesion conditions might be minimised if some or all wheels on the train were allowed a deeper level of slip than the normal 17%-20%. This might improve rail head conditioning. While this is by no means certain, simulation might help to determine if stopping distances could be reduced by employing deeper levels of slip. As increasing the level of slip might cause wheel damage (and damaged wheels can also cause damage to railway infrastructure), deeper levels of slip could only be contemplated for severe low adhesion conditions.

WSP – key issues

151 The analysis contained in paragraphs 140 to 150 has shown that the following is a key issue with regard to WSP systems:

- the longer the train, the greater will be the benefit from rail head conditioning (paragraph 141);
- although the 17-20% slip' parameter for WSP systems is well suited to the reliable stopping of trains in most low adhesion conditions, further consideration of higher and lower levels of slip will help to determine whether an alternative approach is better for severe low adhesion conditions (paragraphs 147-150).

Testing of WSP systems

152 This section addresses the testing of WSP systems. It describes the WSPER® simulator used for testing WSP systems fitted to modern rolling stock operating in this country and compares elements of the WSPER® simulator testing regime with the track-based testing mandated under *International Union of Railways* (UIC) requirements. It also includes some observations on deficiencies within the current WSP testing regime.

153 Testing of WSP systems is required to demonstrate compliance with RGS requirements on air consumption (paragraph 133). Although testing is required, there is no requirement to use a specific test facility or technique. The railway industry in Britain uses AEA Technology's (AEAT) WSPER® simulation and testing facility to test and optimise the performance of WSP systems. The WSPER® consists of a computer control system, a system for emulating the dynamics of the vehicle and its braking system and a transducer. These are connected to a compressor, blowdown valves, pipework and cylinders from (or equivalent to) the system itself. WSPER® is thus a hybrid test rig and simulator. It tests vehicles individually. A normal programme would include simulation of the performance of a single power car and a single trailer car. The data on adhesion conditions within WSPER® is based on the data gathered by the tribometer train in the 1990s (paragraph 123) A validation exercise for the WSPER® was also undertaken in the early 1990's, involving comparisons between braking data from a class 319 EMU on the Midland Main Line and tests on the WSPER®.

154 Paragraphs 131-133 indicate that while WSP systems are mandated on modern disc braked rolling stock there are no quantified stopping criteria contained within RGS against which the performance of WSP systems can be tested.

155 AEAT in conjunction with other railway industry partners including Interfleet and HSBC has developed acceptance criteria for WSP systems tested as part of an approvals programme for new rolling stock. In the first instance, model stopping distances are calculated by WSPER® based on a brake demand that exactly matches the maximum adhesion available at each point along the profile. Acceptance criteria are then developed which permit the WSP system on test to exceed the model stopping distance by a predetermined maximum figure (see paragraph 157). There have been minor revisions to the criteria following reviews of actual performance by WSP systems on test.

156 When WSP systems on new rolling stock are being tested, two types of test are run on WSPER®. The first group of tests simulate 'naturally occurring variable adhesion' conditions, based on adhesion measurements taken across the main line network in the early 1990s. A series of ten simulations are made over a group of adhesion profiles for different load and speed conditions. This value is compared with the actual stopping distance achieved by the WSP to determine how the performance of the WSP system under test compares with the criteria.

157 The results of the ten simulations are considered individually and as a group to establish whether AEAT's criteria have been met:

- individually, the predicted stopping distance of each simulation must not exceed the model value by a percentage that is dependent on the simulated initial speed (eg 90% for an initial speed of 25 mph (40 km/h), 35% for an initial speed of 75 mph (120 km/h));
- collectively, the average predicted stopping distance from the ten simulations must not exceed the model value by a percentage that is dependent on the simulated initial speed (e.g. 27% for an initial speed of 25 mph (40 km/h), 7% for an initial speed of 75 mph (120 km/h)).

158 Other criteria on maximum permissible air consumption and the accuracy of the prediction of speed by the WSP reference wheel also need to be met and there must be no locking up of the wheels above a speed of 6 mph (10 km/h). Performance against these criteria is also assessed using the simulations undertaken on the WSPER® rig.

159 A second set of simulations are undertaken on the WSPER® for sustained low adhesion conditions, defined as 0.02-0.06. For these simulations, the pass or fail criteria with regard to stopping distances described in paragraphs 155 and 157 do not apply. The only criteria used to determine whether a WSP system has passed are air consumption and no locking up of the wheels (as required by RGS GM/RT2044).

160 An alternative test specification for WSP systems is provided by the UIC. A key difference is that the UIC specification (which was first issued in January 1985 and updated in November 2005) requires live testing with levels of adhesion artificially reduced with detergent rather than simulation. Testing of the whole unit takes place rather than simulation of the performance of individual vehicles within the unit. There are differences between the UIC test specification and that used for systems being tested on the WSPER®. Some examples are tabulated in Figure 19:

Parameter	**UIC**	WSPER®
Permissible extension to stopping distance at 75 mph (120 km/h)	25%	35%
Highest permissible speed for lock up	19 mph (30 km/h)	Below 6 mph (10 km/h)
Locking up time limitation	0.4 seconds	None
Level of adhesion simulated	0.05 -0.08	0.02 – 0.14

Figure 19: Comparison between UIC and WSPER test specification.

161 The UIC specification for testing is not favoured in Britain. Early WSP systems used on trains running over the national rail network were tested using the UIC specification. However, the performance of these systems in this country was considered poor (wheelsets were still being damaged) and this provided the impetus for a method of testing that was based on adhesion conditions in this country and the development of the WSPER®.

162 Another reason that WSPER® is preferred in Britain is because there is scepticism about the method by which low adhesion is generated in live testing, which requires the use of a detergent spray immediately in front of the leading wheels of the train being tested. Detergent's properties are not analogous to those of leaf film and the stopping distances generated under test conditions using detergent may be unrepresentative. The actual conditions generated by this method may vary from test to test, depending on weather and environmental factors. There is also a limit as to how low a level of adhesion can be

generated using detergent (around 0.04), whereas adhesion levels of 0.02 and lower have been experienced on the national network. A Euronorm is currently being drafted which covers WSP equipment testing. This currently advocates the UIC approach involving live testing.

163 Failure to meet the WSPER® criteria does not automatically result in a WSP system failing the test, which then raises the issue as to when a system would be considered to have failed. The inclusion of maximum stopping distances within the appropriate RGS (paragraph 133) would help to regularise this situation. However, the development of such criteria would need to be accompanied by the development of a validated, reliable and repeatable test method for demonstrating compliance. This requirement means that live testing is unlikely to be adequate because of the difficulty of producing test conditions that will be the same from one test to the next. Simulation offers a repeatable test method against defined parameters.

164 A number of observations flow from a review of current practice for testing WSP systems:

- Simulation is a good method for providing consistent and repeatable test conditions, which are more difficult to create in a live environment. Their potential use should be recognised within the draft Euronorm on WSP testing. Simulators need to be properly validated before they can be used with confidence to predict the performance of WSP (and other) systems.
- There are no 'whole train' simulators currently available that have been validated to the level necessary to prove that they can accurately predict performance of modern multiple units. This means that there is no certainty that they provide an accurate estimate of the performance of the WSP systems they are testing (paragraph 153).
- The absence of pass and fail criteria for maximum stopping distances under sustained low adhesion conditions means that there is no way of assessing the acceptability of the stopping distance predicted by WSPER® (one of its key objectives) (paragraph 159).
- The adhesion profiles used within WSPER® are based on those that were present on the network in the early 1990s when a tribometer train was operated (paragraph 123). It is possible that measurements taken now would show different adhesion profiles. Simulation should be based on currently-prevailing conditions.
- The predictions of stopping distance provided by simulation tools are currently pessimistic because they only simulate the performance of a single vehicle (the longer the train, the shorter the stopping distance – all other variables being equal), they only take account of the effects of rail head conditioning on a single vehicle (not the whole train) and they do not take accounts of the effects of sanding (paragraph 153).

<u>*Key issues – testing of WSP systems*</u>

165 The analysis contained in paragraphs 153 to 164 has identified the following key issue:

- There is currently no validated model for testing WSP systems that can accurately predict the behaviour of a whole train and the effects of systems such as sanding on the overall stopping distance (paragraph 153).

Sanding

166 This section analyses sanding systems on trains operating over the national railway network and addresses the following issues:

- characteristics and distribution of sanding systems on modern fleets;
- the value of sanding in minimising the extent of overruns during low adhesion incidents;

- the impact of RGS in limiting the amount of sand that can be dispensed by modern units;
- the reasons why there are variations in the characteristics and operating parameters of sanding equipment provided on different fleets;
- sand usage.

167 Sanding equipment is provided on a significant proportion of modern rolling stock and has been mandatory on new rolling stock since 2003. Two basic types of sander are found on units operating over the national railway network. 'Automatic' sanders are fitted to the majority of modern trains. They are triggered by the WSP system without intervention from the driver. 'One-shot' sanding devices are fitted to some modern multiple units (e.g. classes 220 and 221). They are triggered, as required, by the driver.

168 Based on information supplied by the rolling stock leasing companies, of the vehicles operating during autumn 2005, 81.6% were marshalled into multiple units that were equipped with sanding for use in train braking. A further 4.1% in Classes 142-144 and Class 153 comprise units that are specifically barred by RGS from having sanding equipment because they do not have six axles behind the point at which sand must be delivered (paragraph 134).

169 This leaves 14.3% of vehicles permitted to carry sanding equipment that were not doing so in autumn 2005. Of the older fleets, those with the highest populations in this category were Classes 150, 156, 313 and 365. Most modern fleets were equipped with sanders, exceptions in autumn 2005 being Classes 357/0, 458 and 460. Since autumn 2005 further fleets have been equipped with sanders including classes 357/0 and 458. The percentage of vehicles operating on the network within units not equipped for sanding has now fallen to 9% (excluding those barred by current RGS).

170 Only 6.1% of vehicles operating on the national network are marshalled into trains with neither WSP for managing wheelslide during braking nor sanding and they are restricted to Classes 142-144 and Class 153 and some Class 150 and 156 units. The Class 142 was the worst performing DMU class for adhesion-related incidents during 2005 (paragraph 72).

171 Since the late 1990s, a significant influx of new rolling stock onto Britain's main line railway network has occurred, with four TOCs operating intensive services in the south east completely replacing their main line fleets. Considerable variation was apparent between the fleets of rolling stock that were delivered in that time, the key differences in autumn 2005 being summarised below:

- Some fleets had no sanding (Classes 357/0 and 458).
- Some fleets had sanding that was only operative when the driver selects full service (75% braking, equivalent to Step 3 braking on units not fitted with stepless brake controllers) or emergency braking and WSP is active (Classes 444 and 450).
- Some fleets had sanding that was operative when the driver selects Step 2 braking (and above) (Classes 357/2 and 377).
- Some fleets featured continuous sanding once the trigger threshold has been reached, providing WSP remains active and there is sand available to deliver (Classes 360 and 450).
- Some fleets imposed a time limit on sanding, e.g. 10 seconds (Classes 175 and 377), 30 seconds (Classes 321 and 322) and the 2005 modification to the Class 377 units allowed 60 seconds sanding.

- Some fleets were equipped with sanding equipment that can vary sanding rate with the speed of the train. The Class 465/466 units are equipped with variable rate sanders. They work on suburban services in SE London and Kent and are thus subject to frequent station stops. They were ranked 16th out of 32 multiple unit classes in autumn 2005 for low adhesion incidents. This represents a good performance under onerous conditions and indicates the value of higher rate sanding.

172 Tests undertaken by Siemens and SWT at Wildenrath in Germany during January and February 2006 confirm the value of sand in minimising the extension of stopping distances under low adhesion (~0.04) conditions:

- with no sanding employed, the stopping distance for a train travelling at 90 mph (144 km/h) was 1280 metres;
- with sanding active when the brake demand reached or exceeded 75% and train speed was above 19 mph (30 km/h), the stopping distance was 1140 metres (10.9% reduction);
- with sanding active when the brake demand reached or exceeded 40% and train speed was above 10 mph (16 km/h), the stopping distance was 940 metres (26.6% reduction).

173 These results also show that the earlier that sanding is initiated, the more effective it is.

174 The benefits of sanding under operational conditions were illustrated during autumn 2005 by c2c's experience. C2c operates trains between Fenchurch Street and Shoeburyness. In the main, their route follows the line of the River Thames. The service is operated by four-car Class 357 units which were ordered and delivered in two separate batches. The Class 357/0 units (forming 46 of the total fleet of 74 units) were delivered without sanders. The Class 357/2 units (commissioned in 2002, two years after the Class 357/0 units) comprising the remainder of the fleet were delivered with fixed rate sanders fitted.

175 Between 19 October and 26 November 2005, c2c had 26 adhesion-related overruns including one of over 1000 metres (three complete signal sections) at Westcliff on 6 November 2005. C2c's analysis indicated that of the 21 incidents involving four car units, 19 (90%) involved Class 357/0 units although they only comprised 62% of the fleet. In the light of this experience, c2c took the decision to issue amended operating instructions such that the non sander fitted units were operated in 8 or 12 car formation trains whenever possible and that four car trains were formed of sander fitted units. Following this change, the only adhesion-related incident that occurred was with an empty train on a heavily contaminated section of line that had not been subject to rail head treatment. It also involved a unit not fitted with sanding equipment.

176 Following the Lewes SPAD, Southern undertook a detailed analysis of data from the train's *Brake Control Unit* (BCU), which demonstrated that for the short time that sand was available (up to ten seconds), there was a discernible reduction in wheel slip and subsequent improvement in train braking. Duration of sanding is thus a key factor in helping to minimise extensions of overruns during periods of low adhesion. During autumn 2005, Southern Railway implemented a programme of increasing sanding duration on its Class 377 fleet from 10 seconds to 60 seconds. Of 26 incidents affecting Class 377 units in autumn 2005, only three involved units with 60 seconds sanding. Southern Railway has now increased the maximum sanding duration on the Class 377 units to 180 seconds. This is equivalent to the time taken to stop a train from 100 mph (160 km/h) using only step 1 braking and assumes that a braking rate no better than $0.3 m/s^2$ can be sustained throughout, even with the benefit of continuous sanding.

177 RGS GM/RT2461 imposes a requirement that the maximum permissible density of sand on which the last two axles of a train can come to a stand should not exceed 7.5 grammes/metre. This is done in order to avoid excessive sand being deposited on the railhead, which could lead to track circuits failing to detect the presence of a train (paragraph 136) and results in guidance that sanding rates should not exceed 2kg/minute. This is a specific risk with two car units, which only have six axles behind the point at which sand is delivered to clean the sand from the rail head. This also explains why units with less than six axles behind the point at which sand is delivered are currently excluded from having sanders fitted.

178 Some units dispense sand at the rate of 2kg/minute and employ a low speed cut off as well. The Class 444 and Class 450 units are an example, with the low speed cut off threshold in the vehicles as delivered being 18mph (30 km/h). This is likely to have contributed to some of the low speed station overruns that occurred with these fleets (e.g. the incident at Wanborough referred to in Figure 4). The low speed cut-off threshold has now been reduced to 10 mph (16 km/h). A low speed cut-off and restricted sanding rate are exercising control over the same hazard. If a low speed cut-off is provided, it might be possible to increase sanding rates.

179 When sand is dispensed at the rate of 2kg/minute at a speed of 90 mph (144 km/h), less than 1 gramme of sand is delivered for each metre length of rail. For each additional 10 mph (16 km/h) above the 10 mph (16 km/h) threshold, it would be possible to increase sanding rates by 2kg/minute, without the 7.5 grammes per metre length of track threshold being exceeded.

180 In August 2006, Southern Railway undertook low adhesion detergent tests between Dorking and Horsham to quantify the benefits of applying sand at a rate of 3kg/minute. Apart from demonstrating the value of sand per se (from a starting speed of 60 mph (96 km/h) stopping distances were improved by about 33% with sanders operational compared with no sand), the effect of increasing sanding rates to 3kg/minute was to reduce stopping distances by approximately 10% when compared with a sanding rate 2kg/minute under equivalent conditions. Southern has now converted its Class 377 fleet to sand at the higher rate.

181 Given that the sanding rate of 2kg/minute within RGS GM/RT2461 is based on the risk associated with two-car units consideration should be given to the circumstances under which relaxation of the requirements within the Group Standard might be appropriate. As indicated in paragraph 180, Southern has already made a successful case for sanding at a higher rate. The risk of failing to operate track circuits may be lower with units formed of three vehicles or more. Interfleet advises that they undertook some tests with a Class 508 EMU on Merseryrail where a much higher sanding rate than 2kg/minute was applied before problems with track circuit operation were encountered. The AWG has indicated that experience shows that some DC third rail EMUs operating on largely modern AC or jointless track circuits have little propensity for failures to activate track circuits, but disc-braked DMUs operating over DC track circuits have a much higher risk of so doing.

182 There has been inconsistency in provision of sanding equipment within the industry since the late 1990s (at the same time as some fleets were being retrospectively equipped with sanders, new units were being procured without sanding equipment). The RGS lays down base sanding requirements that can be safely applied to all units operating in any part of the network, but as these requirements have been in force for a number of years, there is a need to review them in the light of operating experience. This review might identify changes that could be made to the base requirements or circumstances under which the base requirements could be exceeded.

183 There is also a need to consider new approaches to sanding. Such approaches might include higher sanding rates for use in emergencies, sanding from units other than the leading unit and sanding in front of the leading wheel. Consideration should also be given to whether there are other means of mitigating the risk of trains failing to operate track circuits because of sand between the wheel and rail, including the possible use of contact-enhancing additives to sand dispensed by trains.

184 While sanding up to 2kg/minute is permissible under current standards, some units may, in practice, dispense sand at a significantly lower rate. The report into the adhesion-related SPAD at Esher makes reference to the maximum sanding rate on the unit involved being 1.32kg/minute. At a speed of 90 mph (144 km/h), this is equivalent to a dispensing rate of 0.5 grammes of sand per metre length of rail

185 Changes that TOCs have already made to sanding parameters (commencing sanding earlier, for a longer duration and at a faster rate) may affect sand consumption during autumn, as might changes that TOCs make in response to recommendations contained in this investigation report. It is important that maintenance procedures are reviewed and modified as necessary when changes are made to the operating parameters of key systems such as sanding.

186 Some modern multiple units provide a warning to the driver when sand levels are running low. For example, the Class 444 and 450 units are fitted with a low sand level warning light which is illuminated when there is 20% (approx 5 litres) or less sand remaining in any one sand box. Traincrew are instructed to report all instances of low sand warning light illumination to Fleet Control and Fleet Control will arrange for the unit's sand to be replenished at the first available opportunity.

187 The RAIB has considered whether sand dispensed when the train is travelling at high speed actually reaches the point where wheel meets rail. To investigate this further, SWT arranged for a video to be taken of the sanding nozzle and the wheel during the tests referred to in paragraph 172). The tests demonstrated that the sanding equipment on the Class 450 unit used in the test was effective in delivering sand to the point at which wheel meets rail. Even so, it is incumbent on the maintainers of rolling stock to ensure that the equipment is able to maintain this high level of performance and that the initial system set-up has not been disturbed by day-to-day operation.

Sanding – key issues

188 The analysis contained in paragraphs 167 to 187 has identified the following key issues:

- The application of sand improves the level of adhesion available to trains experiencing difficulties on contaminated rails (paragraph 172). However, not all units are equipped with the facility to lay sand (paragraph 168).
- The configuration of sanders on multiple units was not optimised in autumn 2005 to deal with the conditions encountered. Evidence from testing (paragraph 172) and operational experience (paragraph 176) indicates that benefit is gained from laying sand earlier and continuously while the WSP system is active.
- RGS GM/RT2461 contains base requirements for sanding but there is a need to consider whether those requirements should be updated in the light of operating experience and enhanced to provide guidance on the circumstances under which the base requirements can be exceeded (paragraph 182).
- There is a need for new approaches to sanding to be considered for possible inclusion within RGS GM/RT2461 (paragraph 183).

- Until the review of sanding parameters is complete, it is important that the maximum permitted sanding rates currently allowed by RGS (and existing derogations) are achieved by trains (paragraph 184).
- As changes already made by TOCs to sanding parameters in response to the events of autumn 2005 may lead to increased usage of sand during autumn 2006, it is important that maintenance procedures are reviewed and amended as necessary to address the effects of those changes (paragraph 185).
- Maintenance policy and practice for rolling stock sanding systems should include measures necessary to ensure that the equipment continues to deliver sand to the point where wheel meets rail (paragraph 187).

Braking

189 This section includes:

- a review of the key characteristics of braking systems currently available on multiple units operating over the national railway network in the context of their performance during low adhesion incidents;
- consideration of an alternative braking technology that does not rely on the wheel/rail interface to achieve retardation.

190 Modern trains are equipped with *friction braking* and *dynamic braking*. Disc brakes are employed for friction braking. Dynamic braking (braking of the train by turning the traction motors into generators) is employed in the initial stages of braking and the friction brake is blended in at a later stage to assist the dynamic brake when the brake effort required by the driver cannot be met by the dynamic brake alone. The dynamic brake helps to minimise use of friction braking, thereby decreasing wear and tear on discs and pads.

191 Under low adhesion conditions, the use of the dynamic brake may result in a greater probability of wheelslide occurring initially. This is because the required braking effort is achieved only by wheelsets on bogies equipped with traction motors. If a driver makes a Step 1 brake demand, this is equivalent to $0.3m/s^2$ or the need for a level of adhesion of 0.03 (see paragraph 9) at the interface between wheel and rail if brakes are applied on all wheels. If 50% of the wheelsets are equipped with traction motors and a driver makes a Step 1 brake application with retardation being achieved using the dynamic brake alone, this will result in the equivalent of a brake demand of $0.6m/s^2$ at each motored wheelset. An adhesion level of 0.06 would need to be available if wheelslide was to be avoided. In a situation where 0.04 adhesion was available at the wheel/rail interface, WSP activity would commence immediately if dynamic braking was being used but not if friction braking was effective on all wheels. Without dynamic braking, the train could decelerate at $0.3m/s^2$, but with dynamic braking it will initially decelerate at $0.2m/s^2$ (half of the 'available' $0.4m/s^2$).

192 TOCs have sought to alleviate this problem by configuring the braking system to ensure that if WSP activity occurs, the dynamic brake is inhibited within 3-5 seconds and friction braking is used exclusively. WSP will manage train braking during this period, thus ensuring that retardation is achieved, but at a slightly lower rate than would be the case if friction braking alone was employed.

193 The modification of braking systems to inhibit the dynamic brake when WSP is active has helped to reduce any potentially detrimental effects arising from its use under low adhesion conditions. Given the changes to braking technique implemented by some TOCs

for autumn 2006, which will involve the use of a higher brake step initially (paragraph 220), it will be important that inhibiting the dynamic brake when WSP becomes active is achieved reliably as the change makes it more likely that WSP activity will be experienced initially. Evidence from OTMR downloads can be used to establish whether the process of inhibiting the dynamic brake when low adhesion conditions occur is being achieved reliably. The OTMR downloads seen by the RAIB during the course of this investigation indicate that it is.

194 Disc brakes are provided on modern rolling stock whereas the stock they replaced was equipped with tread brakes. Some drivers have suggested that tread brakes are better than disc brakes at stopping trains in low adhesion conditions because they act directly on the wheel, having the effect of cleaning the wheels and improving adhesion accordingly. This may, in part, be attributable to the fact that tread-braked units achieve deceleration rates of $0.7 m/s^2$, whereas modern disc braked rolling stock can achieve deceleration rates of $1.0 m/s^2$ or greater. Thus the risk of exceeding available adhesion will be greater, although WSP should intervene to ensure that braking rate is matched to available adhesion. It may also be the case that drivers of modern trains are more aware of wheelslide as the display on the driver's desk will indicate if WSP activity is taking place.

195 The AWG low adhesion manual addresses the issue of tread braking and disc braking. Quoting work carried out by British Rail Research in which the relative performance of the two brake types was examined, the AWG Manual makes the following assertions (RAIB comments in brackets):

- Tread braked stock generally has lower operating speeds and lower braking rates than disc braked stock. This can help to create the impression that the brake itself is contributing to better performance.
- When rail conditions are able to support full braking demand, disc brakes are superior to tread brakes (this is borne out by drivers of modern rolling stock who agree that in dry conditions disc braking is more effective).
- When rail conditions are poor (i.e. in drizzle) a good WSP with disc brakes will stop the train in a comparable distance to a tread braked train (this runs counter to the evidence from drivers who have indicated that modern rolling stock was not as effective at stopping under drizzly conditions in autumn 2005 as the tread braked stock that it had replaced).
- When rail conditions are severe a good WSP system will stop the train in a comparable distance to a tread braked train (however, the incident at Lewes on 30 November 2005 described in the Part 2 report suggests that WSP alone is not sufficient when drizzle falls onto a contaminated rail) but will avoid damage to the wheels in so doing, whereas the tread-braked train is likely to suffer wheel damage.

196 Although there may be no evidence to prove that tread braking yields benefits in stopping performance under low adhesion conditions, one advantage of the cleaning effect on wheel treads is to improve electrical contact between the wheel and the rail. For this reason, auxiliary tread brakes (sometimes known as scrubber blocks) were fitted to some disc braked vehicles to aid track circuit operation by cleaning and roughening the wheel treads. There is insufficient evidence to judge whether vehicles equipped with auxiliary tread brakes are less likely to be involved in adhesion-related station overruns because the number of units so equipped is small.

197 One further issue associated with disc braking is the possibility that the lack of cleaning of the wheel surface results in contamination not being cleaned off train wheels, with the attendant hazard that it can be transported around and create adhesion difficulties when the train is required to slow. Currently, wheel swabbing is not systematically undertaken after serious adhesion-related incidents (it was not undertaken after the SPADs at Esher or Lewes) and there is no evidence to evaluate this phenomenon.

198 The friction and dynamic braking systems on rolling stock using the national railway network in Britain are dependent on the level of adhesion available at the interface between wheel and rail. In some European countries (such as Germany and the Netherlands), magnetic braking is employed as an additional means for stopping trains. Magnetic brakes may be used for stopping trains under normal conditions to provide shorter stopping distances with higher speed trains running on lines where signal spacing cannot be adjusted to accommodate higher speeds (and thus it is necessary to shorten stopping distances). They may also be used to minimise stopping distances in emergencies. Similar systems are employed on vehicles operating on some light rail systems in England. A short description of magnetic braking is included in Appendix D highlighting that some forms of magnetic brake require contact between the brake and the track (referred to as magnetic track brakes (MTB), while other forms of magnetic braking are achieved without contact.

199 Research recently conducted for the AWG[7] into the implications of adopting MTBs as a means of stopping trains in an emergency on the national railway network has demonstrated that although there are still some technical issues to be resolved, it is feasible to fit existing units with MTBs. The recommendations in that report include fitting MTBs to a small number of units in order to establish the technical implications and evaluate the costs and benefits.

200 The attraction of magnetic braking is that it offers a potential step change in emergency braking performance. Optimisation of WSP and sanding parameters are worthwhile initiatives and may yield significant benefits in reducing stopping distances. But the incidents at Esher and Lewes both demonstrated that in emergency situations, the length of overrun from a normal stopping point under low adhesion conditions can exceed 1000 metres. For those emergency situations, the ability to utilise a different form of braking (in conjunction with WSP and sanding) has the potential to achieve further significant reductions in stopping distances.

Braking – key issues

201 The analysis of braking systems in the context of low adhesion incidents contained in paragraphs 190 to 200 has revealed the following key issue:

- The experiences of autumn 2005 show that there is scope for further action to address the risk from the most severe adhesion-related incidents. Although the changes made by train operators to sanding and professional driving policies may yield benefits, it may be several years before a final judgement on their effectiveness can be made. In the meantime, there is a need to consider alternative systems that do not rely solely on the wheel/rail interface such as magnetic braking as a means for improving stopping performance in low adhesion conditions (paragraphs 198 - 200).

[7] Interfleet Technology. 'Outline feasibility of fitting magnetic track brakes to UK rolling stock', Report No. ITLR-T17544-001, Issue 1A, 3 April 2006

Summary – rolling stock

202 Paragraph 85 raises the issue of the apparent greater susceptibility of modern rolling stock to adhesion-related incidents based on evidence from recent autumns. There are a number of technical explanations for the apparent greater susceptibility of modern rolling stock to adhesion-related incidents and these have been identified in the summary of key points in the sections on RGS, WSP, sanding and braking. The configuration of sanding equipment can be resolved quickly, but issues such as achieving best use of WSP under sustained low adhesion conditions will require a programme of work to evaluate and resolve.

Operational and Management Factors

Introduction

203 This section considers operational and management factors that influenced adhesion performance during autumn 2005. It considers the following factors:

- procurement and approvals process for new rolling stock;
- TOCs understanding of new rolling stock;
- driving policy and practice;
- driver training and briefing.

Procurement and approvals process for new rolling stock

204 Paragraph 171 highlighted the significant variety in sanding parameters on fleets operating over the national railway network in recent years. Despite this variety, all of the fleets are, compliant with RGS GM/RT2461 (paragraph 134), evidence of the variations permitted by the RGS. It is also indicative of the flexibility in the provisions of the standard that was inherent at the time the fleets were being designed. When procuring new fleets, TOCs prepare a specification. The specification includes, inter alia, performance criteria. However, two recent specifications for new fleets did not contain any clauses on performance criteria for sanding. Decisions on the operating parameters of the equipment were taken by the manufacturers, influenced by the limited performance requirements contained within the RGS.

205 Following the events of autumn 2005, it is apparent that if some TOCs had been more involved in the specification of sanding parameters when new stock was being procured, not only would they have been more aware of the performance characteristics of the system, but they could also have influenced those characteristics and developed their professional driving policies to match the performance of the units (paragraph 216). When procuring new rolling stock, TOCs have general responsibilities under health & safety law to ensure the safety of those affected by their operation (staff, passengers and members of the public). One method of complying is to prepare a specification for new rolling stock and to participate in the development of the design to ensure that the operational risk is reduced to a level that is as low as reasonably practicable.

206 In practice, the input provided by TOCs to this process was inconsistent. A number of TOCs have stated to the RAIB that they now recognise the need for their input into the configuration and operation of sanding systems in the future, utilising the experience that they can bring to the subject. Reference has already been made in paragraph 182 to the need for the RGS on sanding to be reviewed and/or supplemented with guidance. Input from the TOCs to that process will help to ensure that recent experience is reflected in its provisions.

207 The RGS states certain minimum threshold conditions for sanding (e.g. sand must be dispensed in full service and emergency braking). Unless an alternative specification is provided by the TOC or owner of the rolling stock, there would be no reason for the manufacturer to provide sanding that was initiated at a lower brake step. Similarly, the RGS does not specify any requirements for duration of sanding. This has resulted in some manufacturers supplying units with sanding duration limited to 10 seconds. During the late 1990s, the concern to avoid excessive sand being deposited on the rail head (and avoid sand boxes being emptied in a single application) resulted in at least one manufacturer imposing a time limitation on sanding as one way of minimising the risk.

208 In the absence of additional requirements in a specification, a rolling stock manufacturer has only RGS for guidance. A manufacturer offering equipment which dispenses sand in full service and emergency braking only is compliant with RGS GM/RT2461. But there is nothing in RGS GM/RT2461 which prevents a manufacturer from equipping a train with a sander that is operative in Step 2 braking. The only way in which additional provision might be made is if the train owner or operator specified different sanding parameters or the manufacturer supplied them. In all cases, this would require agreement between all relevant parties regarding the value of so doing.

209 The approvals process for new rolling stock requires the use of a VAB to verify compliance with standards. VABs are accredited to perform this role. Given the flexibility of the RGS on sanding, the same VAB could review the design and performance of new fleets with significantly different sanding parameters and conclude that all of them were compliant. Under these circumstances, the VAB has no justification for raising an objection to the design or performance.

210 The same issue relates to stopping distances predicted by WSPER®. WSPER® is used to demonstrate that the standards for air consumption and no wheel lock-up have been met and also that the manufacturer has optimised the WSP equipment to the vehicle. However, it also estimates stopping distances for trains under low adhesion conditions. Paragraph 154 describes how performance criteria have been developed by AEAT and railway industry partners for stopping distances of trains under naturally occurring variable adhesion conditions. As these criteria are not contained within RGS, there is no basis for a VAB to challenge performance of WSP systems. One example was seen of a stopping distance for a new fleet of rolling stock that exceeded the criteria. AEAT argued that because the simulation produced pessimistic estimates of stopping distance (one vehicle only tested, no sanding assumed), the result was still acceptable. The VAB could raise no formal objection to this exceedence as in doing so they would have stepped outside their formal role of reviewing compliance against standards. But it would have been possible for them to comment on this issue, although they did not do so.

TOC understanding of new rolling stock

211 The events of autumn 2005 were affected by some TOCs having an incomplete understanding of the characteristics of their newly- delivered fleet. In one specific example, different views were held by members of the same department on the conditions under which sand was dispensed. In another case, a light on the driver's desk had been labelled 'sanding' and the company believed that when it was illuminated, it indicated that sand was being dispensed. In fact, when illuminated, it indicated that WSP was active; sand would only be dispensed if the appropriate brake step had been selected. In another case, there was confusion among drivers as to how long sanding would be available and whether placing the brake controller into the emergency position would result in sanding being stopped.

212 In the absence of a clear understanding on the part of some TOCs regarding key characteristics of their new rolling stock, it is inevitable that the briefing given to drivers would be affected. Drivers must know when sand is being dispensed during a low adhesion wheelslide incident because sand acts as an adhesion modifier. On all modern rolling stock, the effect of holding a train in the lowest brake step during a wheel slide incident will be that that sand is not dispensed, thereby lengthening the stopping distance of the train.

213 Of equal importance is a driver's understanding of time limits on sanding. If the duration of sanding is limited, drivers need to be able to make a judgement on the value of releasing the brake and reapplying it when the time limit has been reached, which would at least ensure that a second period of sanding becomes available.

Driving Policy and Practice

214 The professional driving polices of TOCs for autumn 2005 emphasised the need for drivers to respond quickly to situations where they may be required to stop their train by braking early but in a low brake step. Many TOCs have encouraged drivers to use brake steps 1 and 2 only during 'normal' driving, with brake step 3 being used as a 'last resort'. When TOCs review driver performance via OTMR downloads, significant use of step 3 braking could be seen as non-compliance with the TOC's professional driving policy.

215 For autumn 2005, the philosophy of 'light and early' was endorsed by most TOCs as appropriate for low adhesion conditions, together with a progressive move through the brake steps if more retardation was required. This technique was correctly used by the drivers involved in the Esher and Lewes SPADs; it can be seen from the OTMR downloads that each brake step was being held for a few seconds before a higher brake step was selected.

216 However, it is also the case that sand is only dispensed in higher brake steps (step 2 or step 3 depending on the fleet). Therefore, the justification for holding a train in a lower brake step when it is sliding is not apparent. A further advantage of moving to a higher brake step quickly is that should the train encounter an area of better adhesion, it will slow more rapidly than would be the case if it were held in a lower brake step. This may help to compensate for the early stages of braking when the train was sliding.

217 Merseyrail has experienced a significant improvement in adhesion performance between autumn 2000 and autumn 2005, in contrast to the deterioration experienced by some other TOCs. In autumn 2000, Merseyrail had 67 adhesion-related station overruns and SPAD incidents. This represented 21.9% of the 306 events recorded that year. In autumn 2005, the worst for adhesion-related in recent history, Merseyrail experienced no station overruns or SPADs attributable to poor adhesion.

218 Merseyrail's driving policy for low adhesion conditions is consistent with the 'light and early' approach adopted by other TOCs. However, they advise their drivers that if they experience adhesion difficulties when step 1 braking is selected, they should immediately place the controller into brake step 3. This ensures that sand is dispensed and that the brakes can take advantage of any improvements in adhesion that become available either through WSP activity, sanding or better rail head conditions.

219 Not all of the dramatic improvement in adhesion performance at Merseyrail can be attributed to the different driving policy (their units have been equipped with sanders since 2000 and they work closely with Network Rail who have made improvements to rail head treatment over the Merseyrail network in the last few years), but the driving policy may have made a contribution.

220 In the first few months of 2006, South Eastern Trains, Southern Railway and SWT worked closely together on methods for improving performance during low adhesion conditions. The three TOCs have now decided that during the autumn low adhesion period, they will adopt a policy of using brake step 2 (40% braking for fleets with stepless brake controllers) rather than brake step 1 initially (a fundamental departure from previous practice). This policy has the advantage that it will allow sand to be dispensed immediately if WSP becomes active on the initial brake application. This policy may be appropriate for adoption by all operators with modern WSP systems.

221 Drivers have expressed the view that the braking characteristics of modern rolling stock were superior to those of older stock during dry conditions. Although the braking policy of TOCs was 'light and early', the possibility that some drivers had become so accustomed to the superior braking performance of modern units during the summer that they were braking much later during autumn was considered. Comparing autumn 2004 and autumn 2005, adhesion-related station overruns increased by more than 150%, but adhesion related SPADs increased by less than 30% possibly indicating a greater reliance by drivers on the capability of the brakes when approaching stations.

222 RAIB reviewed downloads from OTMR equipment to establish whether drivers were complying with the 'light and early' policy. The downloads showed that most, but not all, drivers complied.

223 There is insufficient evidence to estimate the extent of the impact of driving practice on the number of station overruns in autumn 2005, but it is possible that it may have made a contribution.

Driver training and briefing

224 Driver training and briefing practices were described in paragraphs 41 and 42. During the period 2000-2005, a number of TOCs replaced a significant part of their fleet with modern stock. In some cases, this led to a 'cascade' process whereby rolling stock displaced by the introduction of new rolling stock in turn displaced other stock within the same TOC's operation. The net effect of this was to expose a high proportion of drivers within the TOC concerned to rolling stock they had not operated before, with the attendant need for each driver to become accustomed to its characteristics.

225 However, there is no evidence that this was a specific causal or contributory factor to the high number of station overruns in autumn 2005. The introduction of new fleets was complete or well advanced (depending on the TOC) by 2004 and had this been a significant issue, the expectation might have been that performance in 2004 would have been poor, but this was not the case. The issue of driver experience was examined by the AWG in their report into the events of autumn 2005 and they concluded that there was no evidence that driver inexperience had contributed to poor performance in 2005.

Other factors

Operational and Management Factors – Key Issues

226 The analysis contained in paragraphs 204 to 225 has highlighted the following key issues:

- Some train operators had little involvement with the specification of sanding parameters on new rolling stock and this contributed to their variability and suboptimal performance during autumn 2005 (paragraph 204).

- The extensive introduction of new rolling stock and the TOCs' understanding of its characteristics affected the way in which drivers were briefed about handling trains in low adhesion conditions. The professional driving policies employed by TOCs for low adhesion conditions during autumn 2005 were, in some cases, imperfectly aligned with the braking and sanding characteristics of the rolling stock (paragraphs 215 and 216). There is evidence that a strategy of moving to a higher braking step if adhesion problems are encountered is a better way of responding to low adhesion conditions (paragraphs 216-220).

Other factors for consideration

Low adhesion incident investigation

227 There were 331 station overrun and SPAD incidents reported in autumn 2005 that included initial information from Network Rail staff attending on site regarding the presence or otherwise of contaminants. Contamination was observed in 181 (55%) of cases. While this may seem to indicate that contamination is not present in 45% of the incidents recorded, in practice, it points to inconsistency in the way that information is captured after an adhesion-related incident.

228 Currently, there is no standard response to serious incidents caused by low adhesion. A Network Rail MOM attends adhesion-related station overruns and decides on the basis of a visual inspection whether contamination is present. If it is seen to be present, rail head swabs are taken. Rail head swabbing is always undertaken when adhesion-related SPADs have occurred, but there is inconsistency over how many swabs are taken, where they are taken and when they are taken. In the case of the Esher SPAD, some railhead swabbing was not undertaken until 6 hours after the event. Given the transient nature of low adhesion conditions and the fact that many trains had passed over the affected line in the interim, swabbing at this stage would not have yielded meaningful results.

229 There is limited value to be obtained from swabbing, but this is not to say that it is valueless. Occasionally, it can help to identify the source of contamination, distinguishing for example between hydrocarbons such as diesel and mineral oils. But the current swabbing regime relies on a visual examination as an input to the decision on whether to swab or not and this means that if invisible contamination is present, the rail head will not be swabbed even though it is possible that analysis might have been able to reveal something significant.

230 Wheel swabbing is rarely undertaken after adhesion-related incidents. A possible source of evidence is therefore being overlooked. It is unusual to find any reference in industry investigation reports to even a visual inspection of wheels for contamination. In Network Rail's Sussex Route, their MOMs will not undertake wheel swabbing because of concerns over residual current being present. No specific constraint of this nature has been advised by TOCs.

231 When swabbing is undertaken, the results are sent to Scientifics Ltd in Derby for analysis. The process is described in paragraph 48. Although this can help to identify the source of the contamination, there is no way of linking the contamination found with the level of adhesion experienced. Furthermore, as the swabbing test involves the application of distilled water to a pad in order to facilitate removal of solid contaminants, it cannot shed any light on whether the effect of the contamination present had been exacerbated by moisture, such as drizzle.

232 Overall, there is no reliable method for measuring adhesion at sites where incidents have occurred. Data on WSP activity and braking from the OTMR yield valuable information on train speed and stopping distance that enables a train's braking rate to be calculated. However, the OTMR can only give an average value for the level of adhesion rather than an absolute value. In addition, if sanders are working properly the actual level of adhesion available to the train will have improved (use of OTMR data may overestimate the base level of adhesion present). Data from the BCU provides more information about the braking performance of the train including brake cylinder pressures on individual wheels.

233 Procedures governing post-incident investigation of adhesion-related incidents in 2005 were insufficiently detailed to permit a consistent approach to the gathering and processing of information. Procedures did not address the following factors:

- the circumstances under which it is mandatory to gather data;
- what data will be gathered;
- who will be responsible for gathering the data;
- how the data will be gathered, including any conditions to be imposed on train operations over the affected line until the required data has been gathered;
- how data will be processed and by whom;
- how the results will be reported and by whom;
- how the report will be disseminated, to whom and the nature of the follow-up required,
- responsibilities with regard to reviewing the reports and taking appropriate actions.

234 Although there needs to be more thorough investigation of serious adhesion-related incidents, there would be major implications if operations were suspended every time that an overrun occurs. The decision on the depth to which an investigation into an overrun is undertaken should be based on the circumstances and the potential for harm. Any overrun which under slightly different circumstances could have resulted in an accident and overruns of a significant length should be subject to a full investigation. In autumn 2005, there were six station overruns of 1000 metres or more and a further 18 station overruns of 250-999 metres. An investigation regime encompassing all of these incidents would yield very useful data to help in the industry's understanding of adhesion-related events, without having a major impact on operational performance.

Low adhesion data capture

235 Modern trains gather information that is potentially useful in providing key data regarding adhesion-related incidents. Data available from OTMRs, BCUs and Traction Control Units can provide valuable information to enable the actual level of adhesion experienced by the train (as modified by WSP and sanding) to be calculated as well as providing information on how the train's systems performed during the incident. The data can also help to establish the impact of WSP and sanding systems, as was illustrated in the work undertaken by Southern Railway after the Lewes SPAD (see the Part 2 report).

236 Modern rolling stock has the potential to provide current information to the Infrastructure Manager and TOCs about the adhesion status of the railway. The Low Adhesion Warning System (LAWS) is fitted to a small number of units operating over parts of the national railway network (e.g. Central Trains has the equipment fitted to three of its Class 323 units). LAWS can provide current data on adhesion and help to inform rail head treatment policy in the future.

237 If the data gathered by modern trains can be processed and fed back in real time, the enhancement in knowledge for operators is potentially worthwhile. It would enable Network Rail to warn drivers about adhesion problems in specific areas and enable drivers to control their trains accordingly. It would enable rapid deployment of staff or equipment to implement measures to improve adhesion and could also be used to inform the process of determining rail head treatment policy for each of the Network Rail routes. It may be that LAWS can form the basis of such a system, but this remains to be evaluated.

238 A further benefit may be that data from modern trains could be used to provide input to WSP simulator tools (paragraph 164). Data used in simulations must reflect current conditions and there may have been changes from the previously collected data due to the introduction of modern disc braked rolling stock and differences in rail head treatment practice. The data recording capability of modern trains means that it is now possible to quantify levels of adhesion experienced on a daily basis over virtually the whole network.

239 During the investigation, reference was made to the data contained in a recent study into low adhesion conditions that was carried out for the European Rail Traffic Management System (ERTMS) development project. This data was also based on adhesion profiles from the tests undertaken during the 1990s, which may not reflect current conditions.

Conclusions

240 There is no single immediate cause of the high number of adhesion-related SPAD and station overrun incidents that occurred in autumn 2005. There are, however, a significant number of causal and contributory factors.

Causal Factors

241 Significant lengths of low adhesion were experienced on a number of occasions during autumn 2005 and it is possible that they are now occurring more frequently than has been previously thought to be the case (paragraph 123). See Recommendation 18.

242 The approach to the identification of high-risk low adhesion areas on the national rail network was biased towards historical data and recent performance rather than risk arising from the configuration of the infrastructure (e.g. layout of junctions and level crossings) (paragraph 97). See Recommendation 4.

243 Uncertainty over the optimum method for treating the rail head resulted in different methods of treatment being employed across the network. There is contradictory evidence from autumn 2005 with regard to the optimum strategy for railhead treatment (paragraphs 105-109) and further changes made for autumn 2006 need to be validated in terms of their effectiveness (paragraph 112). See Recommendation 5.

244 There was variable performance in the prediction of low adhesion conditions. The overall accuracy of rail head condition prediction using the ADAS system throughout autumn 2005 was unreliable (paragraphs 113 to 115). See Recommendation 6.

245 The application of sand improves the level of adhesion available to trains experiencing difficulties on contaminated rails (paragraph 172). However, not all multiple units are equipped with the facility to lay sand (paragraph 168). See Recommendation 9.

246 Some multiple units are specifically barred from being able to lay sand (paragraph 135). See Recommendation 11.

247 The configuration of sanders on multiple units was not optimised in autumn 2005 to deal with the conditions encountered. Evidence from testing and operational experience indicates that benefit is gained from laying sand earlier (paragraph 172) and continuously while the WSP system is active (paragraphs 172 to 176). See Recommendation 1.

248 RGS GM/RT2461 contains base requirements for sanding but there is a need to consider whether they should be updated in the light of operating experience and enhanced to provide guidance on the circumstances under which the base requirements can be exceeded (paragraph 182) See Recommendation 11.

249 Some train operators had little involvement with the specification of sanding parameters on new rolling stock and this contributed to their variability and suboptimal performance during autumn 2005 (paragraph 204) See Recommendation 13.

250 The extensive introduction of new rolling stock and the TOCs' understanding of its characteristics affected the way in which drivers were briefed about handling trains in low adhesion conditions. The professional driving policies employed by TOCs for low adhesion conditions during autumn 2005 were, in some cases, imperfectly aligned with the braking and sanding characteristics of the rolling stock (paragraphs 215 and 216). There is evidence that a strategy of moving to a higher braking step if adhesion problems are encountered is a better way of responding to low adhesion conditions (paragraphs 216-220). See Recommendation 2.

Contributory Factors

251 There are no criteria within RGS on maximum braking distances under low adhesion conditions (paragraph 133). See Recommendation 10.

Other Issues

252 Further research is required into the mechanisms that create severe low adhesion conditions (including the phenomenon of invisible contamination) and how it can be treated (paragraph 124). See Recommendation 8.

253 As changes already made by TOCs to sanding parameters in response to the events of autumn 2005 may lead to increased usage of sand during autumn 2006, it is important that maintenance procedures are reviewed and amended as necessary to address the effects of those changes (paragraph 185). See Recommendation 1.

254 Maintenance policy and practice for rolling stock sanding systems should include measures necessary to ensure that the equipment continues to deliver sand to the point where wheel meets rail (paragraph 187).

255 There is a need for new approaches to sanding to be considered for possible inclusion within RGS GM/RT2461 (paragraph 183). See recommendation 12.

256 It is important that maximum permitted sanding rates are achieved by trains (paragraph 184). See Recommendation 14.

257 Although the17-20% slip' parameter for WSP systems is well suited to the reliable stopping of trains in most low adhesion conditions, further consideration of higher and lower levels of slip will help to determine whether an alternative approach is better for severe low adhesion conditions (paragraphs 147-150). See Recommendation 16.

258 Longer trains are more likely to be able to benefit from rail head conditioning and thereby reduce stopping distances (paragraph 141). See Recommendation 3.

259 There is currently no validated model for testing WSP systems that can accurately predict the behaviour of a whole train and the effects of systems such as sanding on the overall stopping distance). Simulation offers advantages over live testing and there is a need for the draft Euronorm on WSP testing to recognise the role that simulation can play (paragraph 164). See Recommendation 15.

260 The experiences of autumn 2005 show that there is scope for further action to address the risk from the most severe adhesion-related incidents. Although the changes made by train operators to sanding and professional driving policies may yield benefits, it may be several years before a final judgement on their effectiveness can be made. In the meantime, there is a need to consider alternative systems that do not rely solely on the wheel/rail interface such as magnetic braking as a means for improving stopping performance in low adhesion conditions (paragraphs 198 - 200). See Recommendation 17.

261 Incident investigation is not performed in a consistent or systematic manner, with the result that potential intelligence on adhesion-related incidents is lost (paragraph 233 and 234). See Recommendation 7.

262 Accurate information about real levels of adhesion is increasingly available from modern trains, but is not being exploited to its full potential by the railway industry (paragraphs 235-238). Possible uses of such data include providing real time information to drivers regarding low adhesion conditions and providing data to enable more accurate data regarding rail head conditions to be used in simulation tools for WSP systems. See Recommendation 18.

Observations

263 A recent study into low adhesion conditions was carried out for the European Rail Traffic Management System (ERTMS) development project (paragraph 239). This study refers to data obtained by the tribometer train in the 1990s. This data has not been updated since. See Recommendation 19.

Actions already taken or in progress

264 The industry, through the auspices of the National Task Force commissioned the AWG to undertake an investigation into the events of autumn 2005. The AWG issued its report in April 2006 (known as 'the Goff report'), containing a series of recommendations that are designed to assist in the improvement of performance in autumn 2006. The industry is responding to the recommendations from AWG.

265 Network Rail appointed an individual to assist with the coordination of the industry's response to the recommendations from all investigations into the events of autumn 2005. Appendix E contains a comparison between the recommendations of the Goff report and the recommendations from this RAIB investigation.

266 Individual TOCs (e.g. First ScotRail, First Great Western, c2c) have undertaken reviews into their own performance during autumn 2005 and have identified and implemented their own action plans for autumn 2006. Network Rail and First Group also conducted a joint review of experiences in autumn 2005.

267 Individual TOCs have provided sanding on units that were not equipped last autumn, e.g. c2c on the Class 357/0 units, First ScotRail on the Class 320 units and SWT on the Class 458 units.

268 Individual TOCs have changed the sanding parameters on their fleets to enable initiation of sanding in brake step 2 (or equivalent), e.g. SWT on classes 444 and 450, First ScotRail on Classes 170 and 318.

269 Individual TOCs (e.g. SWT, Southern, Souteastern) have made a fundamental change to the braking policy that will be briefed to drivers. Their drivers will now be instructed to make their initial braking action during autumn in step 2 (40%) rather than step 1.

270 Individual TOCs have undertaken full scale testing of their rolling stock under low adhesion conditions to test various braking, WSP and sanding parameters. SWT conducted trials at Wildenrath in January/February 2006 and Southern Railway undertook tests in August 2006 between Dorking and Horsham. As a result of these tests, changes have been made to sanding parameters on some fleets, for example:

- Southern Railway's Class 377 units and Southeastern's Class 375 units, having initially been converted from 10 seconds to 60 seconds sanding, have now been converted again to permit 180 seconds sanding;
- SWT has converted its Desiro fleet to permit sanding at 40% braking and above, as compared with 75% which applied last autumn;
- Southern Railway and Southeastern have converted their stock to dispense sand at a rate of 3kg/minute, as compared with a rate of 2kg/minute, which applied last autumn.

271 Network Rail has conducted further trials of water jetting and Sandite and, as a result of these trials, will dispense Sandite from their MPV fleet at a higher speed of 40 mph (65 km/h), using a lower concentration of gel. Network Rail has also invested in more than 130 new Traction Gel Applicators for autumn 2005.

272 Network Rail in conjunction with Southern has implemented a programme of trials between Dorking and Horsham during autumn 2006 to assess different rail head treatment strategies. The advantage in using Network Rail infrastructure (as opposed to preserved railways, which have been used for such tests in the past) is that evaluation of effectiveness can be achieved with trains operating at higher (and therefore more realistic) speeds.

273 Network Rail (Wessex route) and SWT have developed a risk-based approach to identifying sites for rail head treatment (or enhanced rail head treatment), that takes account of the consequences of low adhesion incidents at specific locations such as junctions and level crossings as well as their probability. It has been implemented in time to inform rail treatment policy in Wessex, Sussex and Kent routes during autumn 2006 and will be used to inform policy nationally during autumn 2007.

274 Network Rail has worked with ADAS to improve the accuracy of its leaf-fall prediction model. New leaf fall areas have been created to align with Kent, Sussex and Wessex routes and a new area created for the Welsh valleys.

275 Network Rail is funding the trial of a high resolution leaf fall model for the London to Brighton route that will consider tree type, tree density and local topography to a spatial resolution of ¼ mile (400 metres). The accuracy and benefit of the model will be assessed during autumn 2006.

276 Trials are taking place on the Chiltern lines during autumn 2006 of a system that permits local monitoring of rail head conditions as a means of detecting changes that are specific to small areas and alerting Network Rail to specific problem areas that might otherwise go undetected.

277 ATOC has issued a guidance note on the investigation of station overrun and 'failed to call' incidents. Network Rail is aligning its procedures with this guidance note. The guidance indicates that all such incidents should be investigated and that steps such as obtaining BCU downloads can be taken, depending on the seriousness of the incident (paragraph 234).

278 Network Rail is equipping its MOMs' vehicles with an eddy current measuring device to allow immediate measurement of the thickness of leaf fall contamination following an incident.

279 Some TOCs are operating longer train formations where their own analysis shows that it is a reasonably practicable response to the risk associated with low adhesion conditions.

280 Network Rail at route level and individual TOCs have been working together to agree aspects of the autumn adhesion strategy, including locations of static equipment and a vegetation control plan.

Recommendations

281 The RAIB sent the recommendations 1-7 to the railway industry on 6 July 2006 to enable relevant parties to consider their contents and take action that they considered to be appropriate for autumn 2006. Some modification has been made to the wording of recommendations 2, 4, 6 and 7 to take account of action taken in the interim, clarify intent or facilitate the logical grouping of related issues.

282 The recommendations affect the railway as a system and many parties within the railway industry. The RAIB considers that:

- Network Rail and train operators should coordinate their activities with each other and with parts of the railway industry affected by the recommendations to ensure the optimum response;
- where it has been recommended that the implications of changes are assessed and implemented if appropriate, the assessment should consider the effect on systems and interfaces;
- where recommendations affect subjects that are currently addressed by existing or emerging TSIs and Euronorms, the findings from work performed in response to the recommendation should be fed into the appropriate European drafting committees.

283 The following safety recommendations are made[8].

Short Term

1. Train operators to:

   - make modifications to multiple units already fitted with sanding equipment to permit application of sand in brake step 2 and above (or the equivalent of brake step 2 and above on multiple units fitted with step-less brake controllers) for the duration of the period when the WSP system is active on the leading vehicle (paragraph 247);
   - adjust, as appropriate, rolling stock maintenance activities during the autumn low adhesion period to include enhanced monitoring of sand hoppers to ensure that sand is always available (paragraph 253);
   - review their maintenance polices and practices for sanding systems to check that they are targeted at ensuring that the system continues to deliver sand to the point where wheel meets rail (paragraph 254).

continued

[8] Responsibilities in respect of these recommendations are set out in the Railways (Accident Investigation and Reporting) Regulations 2005 and the accompanying guidance notes, which can be found on RAIB's web site at www.raib.gov.uk

2. Train operators to:

   - Modify as appropriate their instructions to drivers regarding the braking of trains equipped with a WSP system in low adhesion conditions to ensure that if the expected level of retardation is not achieved during the initial stage of braking, the optimum position of the brake controller is immediately selected to maximise braking efficiency. This may involve selecting a full service brake application or, where appropriate, an emergency brake application.

   - Brief any revised instructions to drivers (paragraph 250).

3. Train operators of multiple units operating in single unit formations to consider increasing the length of train consists during the autumn low adhesion season where reasonably practicable, e.g.:

   - where rolling stock is available;

   - where platforms can accommodate longer trains;

   - where, based on the train operator's review of low adhesion events and knowledge of problem areas for adhesion, there is a demonstrable benefit in so doing on specific routes and/or at specific times of day (paragraph 258).

4. Network Rail to develop and implement a risk-based strategy for rail head treatment and vegetation control in consultation with train operators. The strategy should be based on a review of recent data and take particular account of locations such as the approaches to junctions and level crossings where the consequences of an overrun could be severe. At high risk locations such as junctions, level crossings and steep gradients, consideration should be given to one or more of the following solutions:

   - the targeted application of Sandite;

   - application of Sandite using strategically placed fixed applicators;

   - temporary restrictions in operational use (e.g. avoiding the use of a junction);

   - temporary modification of signalling controls to extend effective overlaps beyond signals;

   - instructions to selected trains to perform running brake tests in order to assess the state of adhesion;

   - other effective measures defined by parties involved in managing the risk from low adhesion (paragraph 242).

5. Network Rail to:

   - plan and execute trials in conjunction with train operators to validate changes made to rail head treatment for autumn 2006 and assess potential adjustments for autumn 2007 (paragraph 243);

   - develop a strategy for rail head treatment in consultation with TOCs, based on the outcome of the trials (paragraph 243).

continued

6. Network Rail to conduct a review with ADAS to determine the scope for improving the accuracy of low adhesion prediction (paragraph 244).

7. Network Rail and train operators to develop a joint strategy for investigating adhesion related overrun and SPAD incidents that addresses:
   - Which low adhesion incidents are investigated;
     - criteria for undertaking an investigation (e.g. length of overrun, potential severity of outcome);
     - whether different levels of investigation are appropriate and if so, the criteria that apply to each one.
   - What data is gathered, when, how and by whom;
     - justification for gathering each item of data;
     - when wheel swabbing is appropriate and clear guidance on the extent and number of rail swabs to be undertaken;
     - train data recorders;
     - brake Control Unit;
     - traction Control Unit;
     - Network Rail and TOC staff responsibilities.
   - Whether enhancements can be made to existing swabbing techniques to improve the value gained from swabbing;
   - Management of investigations;
   - Use of alternative approaches or technology to estimate levels of contamination and/or adhesion available (paragraph 261).

Medium/Long Term

8. RSSB to extend research and testing into how severe low adhesion conditions occur with particular reference to the phenomenon of micro layers of contamination on rail surfaces, invisible to the eye. The research will seek to establish the nature of the contaminant, how it reaches the rail and bonds with it, the circumstances under which the contaminant poses a particular threat to train braking (e.g. the factors that exacerbate its impact), the factors that determine how long it endures, possible methods for identifying its presence and methods for preventing its formation and dispersing it (paragraph 252).

9. Train operators to fit automatic sanding equipment to those multiple units of five cars or less that are not currently so equipped, unless they are specifically excluded from doing so by GM/RT2461 (paragraph 245).

continued

10. RSSB to lead research into ways of deriving quantitative criteria for braking performance under low adhesion conditions and the implications of each identified approach (including the potential impact on railway infrastructure). The research should include a consideration of the levels of adhesion against which performance (e.g. stopping distances or deceleration rates) should be demonstrated (paragraph 251). The implications of adopting the approach proposed in the draft second issue of the high speed rolling stock TSI should be considered. The results from the research should be incorporated into the relevant RGS as appropriate and disseminated to those who are revising the high-speed rolling stock TSI.

11. RSSB to review the relevance of existing sanding parameters within GM/RT 2461 (paragraph 248) and amend, enhance or supplement them with additional guidance where appropriate. The review is to encompass:

    - implications (cost, benefits and disbenefits) of increasing the guide value of 2kg/minute for maximum sanding rate (taking account of the trials undertaken during August 2006 by Southern Railway);
    - the current sanding initiation threshold (full service and emergency braking) and the effect of reducing it to Step 1 or equivalent value for trains equipped with stepless brake controllers;
    - the need for criteria covering minimum sanding duration;
    - the need for criteria on sanding at low speeds including the implications of permitting sanding until the train has come to a stand;
    - identification of ways in which currently excluded vehicles (e.g. Classes 142-144, 153) can be equipped with sanders (paragraph 246).

12. RSSB to carry out research in conjunction with Network Rail and train operators into the implications, (cost, benefits and disbenefits) of:

    - adopting enhanced sanding rates under emergency conditions above a defined speed threshold (either activated manually by the driver or automatically activated by the placing of the brake controller into the emergency position when WSP is active);
    - allowing leading wheel sanding for high speed emergency braking;
    - permitting units other than the leading unit to dispense sand under emergency conditions;
    - methods of avoiding the problem of excessive sand causing failures to operate track circuits (e.g. use of different materials or additives) (paragraph 255).

13. Train operators to ensure that until RGS GM/RT2461 has been reissued, clauses on sanding are contained within specifications for new rolling stock. TOCS should specify, as a minimum, the requirement for continuous sanding while WSP is active in Brake Step 2 (or equivalent for trains equipped with stepless brake controllers) and above and a sanding rate of 2kg/minute (paragraph 249).

continued

14. Train operators to check the sand dispensing rate of each train within their fleets and ensure that it is set to the RGS GM/RT2461 guidance value of 2kg/minute except where a higher value has been permitted (paragraph 256).

15. RSSB to establish a project to:

- Measure the accuracy of existing WSP simulation rigs that could be used to support rolling stock approvals. This validation should include reference to records obtained from train data recorders following actual incidents and full-scale testing as appropriate. The latter should include a direct comparison between UIC detergent test data and a simulation of the same (paragraph 259).
- Examine the feasibility of extending the capability of an existing WSP simulation tool in order to predict more accurately the behaviour of an entire train in low adhesion conditions (e.g. allowing for rail head conditioning, the effect of sanding and more than one vehicle) (paragraph 259).

The results from the project should be used to inform the developing Euronorm on WSP equipment testing (paragraph 259)

16. Subject to the successful development of the simulation tool described in Recommendation 15, RSSB to undertake a programme of modelling to evaluate the impact of different control strategies for minimising stopping distances under various low adhesion conditions. The simulation should specifically address potential alternative strategies for extreme circumstances including:

- changing WSP control algorithms for the level of slip permitted from the current value of 17-20%;
- permitting different levels of slip on wheels on the same train to optimise overall braking during low adhesion conditions.

All the simulations should be designed to evaluate the effect of different strategies on braking performance and rail head conditioning and should include simulations with sanding operative (paragraph 257). The results from the programme should be shared with those responsible for drafting relevant high-speed and conventional TSIs for possible inclusion in new or revised versions of those documents.

17. RSSB to initiate a project to evaluate the costs and benefits of equipping multiple units operating over the British mainline network with magnetic track brakes for use in emergencies under low adhesion conditions. The project will:

- Address and resolve the outstanding issues identified in Interfleet report ITLR-T17544-001.
- Subject to successful resolution of outstanding issues, specify and procure magnetic track brake (MTB) equipment and fit it to a small number of units. The units chosen should represent different traction types with different operating regimes and operate in different geographical areas.

continued

- Develop and implement trials of these units, incorporating in-service experience and specific comparative tests with a similar unit not equipped with MTB.

The project will aim to determine whether MTBs are a cost effective solution for new-build rolling stock and/or retrofitting to existing rolling stock (paragraph 260).

18. RSSB to establish a study into the potential uses of systems on modern rolling stock to:

- automatically sample adhesion conditions, e.g. by the controlled braking/release of a single wheel-set on service trains (other than during train braking) (paragraph 235);
- establish the profile, nature and distribution of low adhesion conditions on the national rail network currently and provide input to WSP simulation packages (paragraph 241);
- improve intelligence about adhesion conditions in real time, e.g. use of wireless data transmission to feed details of low adhesion conditions encountered during braking to a monitoring system. (paragraph 262).

The study should take into account operating experience with the Low Adhesion Warning System (LAWS) and consider the lessons learnt in relation to the development of a network wide solution for monitoring low adhesion conditions. The study should be developed in the context of the work currently being undertaken by RSSB in research project T540, 'Scoping and Development of the Adhesion Management System'. The output from this study must include consideration of how the information can be used by the railway industry including the need for signallers and drivers to be made aware of low adhesion conditions in real time.

19. Network Rail to review ERTMS low adhesion assumptions in the light of the findings of this report and consider whether any changes are needed to ERTMS design or operating parameters in the light of the review (paragraph 263).

Appendices

Glossary of abbreviations and acronyms — Appendix A

AEAT	AEA Technology
AHBC	Automatic Half Barrier Crossing
ATO	Automatic Train Operation
AWG	Adhesion Working Group
BCU	Brake Control Unit
DMU	Diesel Multiple Unit
EEC	European Economic Community
EMU	Electric Multiple Unit
ERTMS	European Rail Traffic Management System
LAWS	Low Adhesion Warning System
MOM	Mobile Operations Manager
MPV	Multi Purpose Vehicle
MTB	Magnetic Track Brakes
OTMR equipment	On Train Monitoring and Recording equipment
RAIB	Rail Accident Investigation Branch
RGS	Railway Group Standard
RSSB	Rail Safety & Standards Board
SMIS	Safety Management Information System
SPAD(s)	Signal(s) Passed At Danger
SWT	South West Trains
TEN	Trans European Network
TOC	Train Operating Company
TSI	Technical Specification for Interoperability
UIC	International Union of Railways
VAB	Vehicle Acceptance Body
WSP system	Wheelslide Prevention system
WSPER®	WSP Simulator Rig

ADAS Classification System	System developed by ADAS UK Ltd and used by Network Rail to classify the risk from leaf-fall on each day during the autumn for discrete geographical areas of the national railway network.
Adhesion Working	Cross-railway-industry focus group with the sole objective of researching and developing initiatives to combat the effects of low wheel/rail adhesion and promoting awareness of the low adhesion issue within the industry and its key stakeholders.
Automatic Train Operation (ATO) mode	A system of train control that involves communication between the train and track-based equipment to initiate acceleration, coasting and braking as appropriate and maintains safe separation between all trains operating on the route.
Blowdown valves (also known as dump valves)	Valves provided to regulate air pressure for the purposes of rapidly applying and releasing brakes during WSP activity.
Brake Control Unit	Interface between the driver's brake controller and the train brakes, WSP equipment and sanding, converting brake demands from the driver into brake cylinder pressures (via an analogue control unit). The BCU also contains a microprocessor which manages the brake blending process and logs any faults that have occurred within the braking, WSP and sanding systems.
Braking (step 1, step 2, step 3)	Different positions on the driver's brake controller representing progressively greater brake demands, e.g. brake step 1 is analogous to a retardation rate of $0.3m/s^2$, brake step 2 to a retardation rate of $0.6m/s^2$ and brake step 3 to a retardation rate of $0.9m/s^2$.
Company Procedure (Network Rail)	A document that provides details of the procedure to be followed by Network Rail staff in order to comply with the requirements of a Railway Group Standard.
Conditioning (the rail head)	The process by which a contaminated railhead may be cleaned by the friction caused by train wheels passing over.
Diesel Multiple Unit	A self-contained diesel-powered train comprising one or more vehicles that can be coupled to other compatible diesel multiple units to form longer trains.
Dynamic brake/braking	A brake which operates by using the traction motors as electrical generators to slow down a train.
Electric Multiple Unit	A self-contained train powered by electricity gathered from overhead line equipment or conductor rails comprising one or more vehicles that can be coupled to other compatible electric multiple units to form longer trains.
Friction brake	A brake which operates by using friction to slow down a train, e.g. tread brakes which involve a metal block making contact with the tread of the wheel or disc brakes which involve contact between a pad and a disc located on the axle.

International Union of Railways	An international railway union comprising various railway companies and administrations to agree common standards and practices.
Late notice arrangements	A means of providing train drivers with information of a short-term or emergency nature at the time they commence their driving shift.
Mobile Operations Manager	A member of Network Rail's staff whose duties include rapid deployment to incidents and accidents to assist in the process of restoring the railway to normal operations and investigating the cause of the incident/accident.
Multi-Purpose Vehicle	Two power units placed at either end of a fixed formation train conveying, for example, containers or tanks. For the purposes of railhead treatment in Sussex during autumn 2005, they conveyed two containers, one with water which is jetted at high pressure onto the rails to clean the railhead and one with Sandite which is applied to the rails to improve adhesion.
On Train Monitoring and Recording Equipment	An on-board computer that records the status of different items of equipment in real time and enables a plot of train performance and driver actions to be downloaded.
Professional driving policy	A policy prepared by TOCs that describes, inter alia, train driving practices that the company expects its drivers to adopt in order to ensure safe and efficient train operations.
Railway Group Standards	Mandatory technical or operational document which sets out what is required to meet system safety responsibilities on Network Rail's infrastructure.
Rail Safety & Standards Board	A body established on 1 April 2003 with the objective of coordinating the railway industry's work in achieving continuous improvement in the safety performance of the national rail network.
Rule Book	A book which incorporates most of the rules to be observed by general railway staff for the safe operation of the railway.
Safety Management Information System	A database maintained by the RSSB which includes details of incidents and accidents occurring on the national rail network.
Sandite	A suspension of sand and steel particles in a gel applied to the railhead by MPVs and Rail Head Treatment Trains during the autumn leaf-fall season to improve adhesion conditions for trains.
Sectional appendices	Network Rail document containing local rules and instructions and details of the railway for a given part of the network.
Stepless brake controller	A brake controller that allows the driver to make fine adjustments (from 1% to 100%) in the amount of braking demanded.
Technical Specifications for Interoperability	European legislation which mandates certain minimum common standards across the European Union to facilitate inter-working of trains between member countries.

Track circuit	An electrical device using rails in an electric circuit which detects the absence of trains on a defined section of line.
Train detection	A means for detecting the presence of a train on a specific part of a route. Track circuits are one means of train detection, as are axle counters.
Train path	The planned schedule over the network for a train
Train Operating	A company that is franchised to run train services over a designated area of the national rail network.
Trap points	A set of points designed to derail a train that has passed the protecting signal at danger rather than allowing it to proceed onto a running line where it could collide with another train.
Tribometer train	A train that with specialised equipment on board to measure the adhesion available between wheel and rail.
Vehicle Acceptance Body	An accredited body that, inter alia, reviews the design of new rolling stock and confirms that it complies with standards.
Wheelslide prevention system	A system which, when active during braking, identifies when train wheels have started to slide and releases and reapplies brakes to: ● optimise braking rate to the level of adhesion available; ● condition the rail head (see separate definition).
WSPER®	A simulator operated by AEA Technology which is used to test and optimise the performance of WSP systems.

Key standards current at the time — Appendix C

GE/RT8000	Rule Book
GE/RT8040	Low adhesion between the wheel and the rail – managing the risk
GM/RT2461	Sanding equipment fitted to multiple units and on-track machines
GM/RT2044	Braking system requirements and performance for multiple units
GM/RT2045	Braking principles for rail vehicles
GO/RT3252	Signals passed at danger

An overview of magnetic brakes[9] — Appendix D

Magnetic brakes are used extensively on light rail systems but there are also significant uses of the technology in heavy rail applications and high speed operations in Europe. Magnetic brakes can be divided into two types, those that achieve retardation by physical contact between brake and rail (this type is used extensively in Germany and the Netherlands) and those that work without contact between brake and rail (this type is less widely used but is provided on the ICE3 high speed inter-city trains in Germany).

Magnetic track brakes using physical contact between brake and rail

There are two types of magnetic track brake (MTB) that work by establishing physical contact between the brake and the rail head, the difference being the use of either an electromagnet or a permanent magnet.

- The electromagnetic type uses an energised coil to create a magnetic attraction force to bring pole shoes into contact with the rail.
- The permanent magnet type uses electrical, hydraulic or pneumatic switching of the magnetic field to bring pole shoes into contact with the rail.

For main line applications, the MTB is normally suspended from the bogie frame, with the contacting shoes positioned 60-130mm above the rail. The frame that supports the magnet is held to the bogie frame by springs within the brake actuators. When the brake is demanded, the actuators lower the frame at the same time as the magnets are energised or switched, depending on magnet type.

The retardation achieved is dependent on the attraction strength of the magnet and the coefficient of friction between the contacting shoes and the rail head. The coefficient of friction is determined by a number of factors, including the condition of the rail surface, speed and contact pressure. For emergency braking use, the magnetic strength would normally be as high as possible commensurate with stopping the train as quickly as possible without injuring passengers in the process, and assuming that the strength was compatible with other lineside systems and services. MTBs could also be used to condition the railhead during normal service braking, but the magnetic strength would then be reduced in order to achieve the objective without causing passenger discomfort.

Magnetic brakes that do not use physical contact between brake and rail

The eddy current brake works without physical contact with the rail. An energised coil located in close proximity to the track creates eddy currents which provide a retardation force without any contact. This makes the eddy current brake able to function irrespective of the surface condition of the rail. The eddy currents induced do, however, cause the temperature of the rail to rise. In extreme circumstances, this could result in buckling of the rail. Any use of an eddy current brake should be based on the need to ensure that rail temperatures are not raised to a critical level. The issue of rail heating is not insurmountable as the eddy current brake is used in Germany for service braking on high speed trains.

[9] This overview is based on the contents of a document prepared by Interfleet Technology Ltd for the Rail Safety and Standards Board (RSSB) titled 'Outline feasibility of fitting magnetic track brakes to UK rolling stock', Report No. ITLR-T17544-001, Issue 1A, 3 April 2006.

Reasons for preferring magnetic track brakes for trials on the national railway network

ECBs will perform consistently irrespective of rail head contamination, and this is a major advantage over MTBs. However, the contact that MTBs make with the rail head, although affected by the extent of contamination, will provide some additional benefit through conditioning of the rail head which improves adhesion for following wheels.

The performance of ECBs is highly sensitive to the extent and integrity of the maintenance they receive. It is critical that the correct airgap is maintained between the ECB and the surface of the rail. This means that readjustment of the airgap is necessary for wheel wear and wheel turning for example. The dimensions of the airgap must be monitored constantly as the wrong values could compromise the performance of the system

A supplier of ECBs also advises that:

- ECBs require a significantly greater power supply than MTBs. MTBs require about 1kW per magnet (vehicle batteries can provide this even in the face of total traction power supply loss) while ECBs require about 40 kW per magnet. For ECBs a major strengthening of the vehicle auxiliary power supply would be required.
- It is possible that ECBs will increase axleloads significantly when they are active, unlike MTBs which have no such influence. This is due to the fact that in creating the stopping electro motive force a large attractive force is produced between pole shoes and the rail. The train's suspension is used to resist this and maintain a typical airgap of 6-7 mm between pole shoe and rail. This must be taken into account when designing wheelsets and bogie frames.

In addition to the possible concerns regarding ECBs indicated above, the RAIB believes that MTBs are a more suitable choice for testing on the main line railway network because:

- There is greater experience of their use internationally than is the case for ECBs and this helps to provide confidence in the technology;
- The assessment of the implications of their use on the national railway network is more advanced than is the case for ECBs

Comparison between recommendations in the AWG and RAIB investigations into low adhesion events during autumn 2005

Appendix E

The table below provides a comparison between the recommendations contained in the AWG's investigation into low adhesion events during autumn 2005 (the 'Goff report') and the recommendations contained in this report.

	AWG Recommendation	RAIB Recommendation
1	NR should develop a rail treatment strategy that is consistent with its own research and that optimizes the advantages of available methods of treatment as well as the versatility of its equipment.	**5** **Network Rail** to: • plan and execute trials in conjunction with train operators to validate changes made to rail head treatment for autumn 2006 and assess potential adjustments for autumn 2007 • develop a strategy for rail head treatment in consultation with TOCs, based on the outcome of the trials
2	NR should construct a rail treatment programme that is consistent, capable of delivery, and not compromised by conflict with engineering possessions.	Implicit in recommendation 5
3	NR should ensure that its own and its contractors' resources are sufficient to deliver the programme as planned.	No equivalent RAIB recommendation
4	NR should share with TOCs the results of its research into methods of rail treatment, and the logic of its strategy.	Implicit in recommendation 5
5	NR should undertake further research into the nature of residual contamination following water jetting.	No equivalent RAIB recommendation
6	NR should, in conjunction with TOCs, monitor the delivery of rail treatment on a local basis.	Implicit in recommendation 5

AWG Recommendation	RAIB Recommendation
7 NR should review systematically with TOCs the location of rail treatment sites to ensure that they reflect the needs of modern rolling stock, and that the sites of poor adhesion shown in the Sectional Appendix reflect the present situation.	**4** **Network Rail** to develop and implement a risk-based strategy for rail head treatment and vegetation control in consultation with train operators. The strategy should be based on a review of recent data and take particular account of locations such as the approaches to junctions and level crossings where the consequences of an overrun could be severe. At high risk locations such as junctions, level crossings and steep gradients, consideration should be given to one or more of the following solutions: • - the targeted application of Sandite; • - application of Sandite using strategically placed fixed applicators; • - temporary restrictions in operational use (e.g. avoiding the use of a junction); • - temporary modification of signalling controls to extend effective overlaps beyond signals; • - instructions to selected trains to perform running brake tests in order to assess the state of adhesion • - other effective measures defined by parties involved in managing the risk from low adhesion
8 NR should carry out, in conjunction with TOCs, a systematic review of lineside vegetation, and develop local, prioritized, programmes for treatment.	Covered by recommendation 4

AWG Recommendation	RAIB Recommendation
9 NR should review the effectiveness of swab testing as a realistic means of providing post incident information, and if necessary develop a procedure that specifies how and when swabs should be taken and how the results should be interpreted	**7** **Network Rail and train operators** to develop a joint strategy for investigating adhesion-related overrun and SPAD incidents that addresses: • Which low adhesion incidents are investigated: o criteria for undertaking an investigation (e.g. length of overrun, potential severity of outcome); o whether different levels of investigation are appropriate and if so, the criteria that apply to each one. • What data is gathered, when, how and by whom: o Justification for gathering each item of data; o When wheel swabbing is appropriate and clear guidance on the extent and number of rail swabs to be undertaken; o Train data recorders; o Brake Control Unit; o Traction Control Unit; o Network Rail and TOC staff responsibilities. • Whether enhancements can be made to existing swabbing techniques to improve the value gained from swabbing; • Management of investigations; • Use of alternative approaches or technology to estimate levels of contamination and/or adhesion available.
10 TOCs operating fleets not equipped with sanders should develop business cases for their fitment, where permitted by Railway Group Standard GM/RT2461.	**9** **Train operators** to fit automatic sanding equipment to those multiple units of five cars or less that are not currently so equipped, unless they are specifically excluded from doing so by GM/RT2461

AWG Recommendation	RAIB Recommendation
11 TOCs operating fleets with sanders should ensure that the equipment fully exploits the scope allowed by Railway Group Standard GM/RT2461.	**1 Train operators to:** • make modifications to multiple units already fitted with sanding equipment to permit application of sand in brake step 2 and above (or the equivalent of brake step 2 and above on multiple units fitted with step-less brake controllers) for the duration of the period when the WSP system is active on the leading vehicle • adjust, as appropriate, rolling stock maintenance activities during the autumn low adhesion period to include enhanced monitoring of sand hoppers to ensure that sand is always available • review their maintenance policies and practices for sanding systems to check that they are aimed at ensuring that they system continues to deliver sand to the point where wheel meets rail 12 **RSSB** to carry out research in conjunction with Network Rail and train operators into the implications, (cost, benefits and disbenefits) of: • adopting enhanced sanding rates under emergency conditions above a defined speed threshold (either activated manually by the driver or automatically activated by the placing of the brake controller into the emergency position when WSP is active) • allowing leading wheel sanding for high speed emergency braking • permitting units other than the leading unit to dispense sand under emergency conditions • methods of avoiding the problem of excessive sand causing failures to operate track circuits (e.g. use of different materials or additives) 11 **RSSB** to review the relevance of existing sanding parameters within GM/RT 2461 and amend, enhance or supplement them with additional guidance where appropriate. The review is to encompass: • Implications (cost, benefits and disbenefits) of increasing the guide value of 2kg/minute for maximum sanding rate (taking account of the trials undertaken during August 2006 by Southern Railway) • The current sanding initiation threshold (full service and emergency braking) and the effect of reducing it to Step 1 or equivalent value for trains equipped with stepless brake controllers; • The need for criteria covering minimum sanding duration; • The need for criteria on sanding at low speeds including the implications of permitting sanding until the train has come to a stand; • Identification of ways in which currently excluded vehicles (e.g. Classes 142-144, 153) can be equipped with sanders **14 Train operators** to check the sand dispensing rate of each train within their fleets and ensure that it is set to the RGS GM/RT2461 guidance value of 2kg/minute except where a higher value has been permitted

AWG Recommendation	RAIB Recommendation
12 ATOC Engineering Council, together with TOCs operating Class 170 fleets, should identify and resolve any problem with WSP performance.	No equivalent RAIB recommendation
13 ATOC Engineering Council should consider the establishment of performance criteria for train braking systems in low adhesion conditions for use when specifying new and modified rolling stock.	10 **RSSB to** lead research into ways of deriving quantitative criteria for braking performance under low adhesion conditions and the implications of each identified approach (including the potential impact on railway infrastructure). The research should include a consideration of the levels of adhesion against which performance (e.g. stopping distances or deceleration rates) should be demonstrated. The implications of adopting the approach proposed in the draft second issue of the high speed rolling stock TSI should be considered. The results from the research should be incorporated into the relevant RGS as appropriate and disseminated to those who are revising the high-speed rolling stock TSI
14 Where dynamic brakes are used, TOCs should ensure that driver training and briefing fully address their characteristics in poor adhesion conditions	No equivalent RAIB recommendation
15 TOCs should ensure that, where appropriate, driver instructions provide guidance on class-specific characteristics, including the behaviour of single unit formations.	No equivalent RAIB recommendation
16 ATOC Operations Council should review the appropriateness of clause 5.4 in Guidance Note 007 in relation to braking techniques when stopping at through stations.	No equivalent RAIB recommendation
17 ATOC Operations Council should review the appropriateness of the initial use by drivers of brake step 1 in conditions of poor adhesion. .	2 Train operators to: • Modify as appropriate their instructions to drivers regarding the braking of trains equipped with a WSP system in low adhesion conditions to ensure that if the expected level of retardation is not achieved during the initial stage of braking, the optimum position of the brake controller is immediately selected to maximize braking efficiency. This may involve selecting a full service brake application or, where appropriate, an emergency brake application. • Brief any revised instructions to drivers.

AWG Recommendation	RAIB Recommendation
18 TOCs should review their autumn plans to increase the length of train formations where appropriate	**3** **Train operators** of multiple units operating in single unit formations to consider increasing the length of train consists during the autumn low adhesion season where reasonably practicable, e.g.: • where rolling stock is available • where platforms can accommodate longer trains • where, based on the train operator's review of low adhesion events and knowledge of problem areas for adhesion, there is a demonstrable benefit in so doing on specific routes and/or at specific times of day
19 TOCs should develop procedures for post incident investigation of station overruns, ensuring that both operating and fleet expertise, as well as drivers, is routinely involved.	Addressed by RAIB recommendation 7
20 If the industry considers that station overruns are a major safety risk, it should institute a procedure for the reporting and investigation of such events, to assist monitoring and understanding of underlying causes. A definition of station overrun should be agreed.	Addressed by RAIB recommendation 7
21 The industry should commission research designed to provide an understanding of the "wet rail" phenomenon	8 **RSSB** to extend research and testing into how severe low adhesion conditions occur with particular reference to the phenomenon of micro layers of contamination on rail surfaces, invisible to the eye. The research will seek to establish the nature of the contaminant, how it reaches the rail and bonds with it, the circumstances under which the contaminant poses a particular threat to train braking (e.g. the factors that exacerbate its impact), the factors that determine how long it endures, possible methods for identifying its presence and methods for preventing its formation and dispersing it
22 The industry should commission work to establish the extent to which wheel contamination is a problem.	No equivalent RAIB recommendation

AWG Recommendation	RAIB Recommendation
23 The industry should continue to develop ways of providing location specific adhesion forecasts that are relevant to the needs of infrastructure maintainers and drivers.	**7** **Network Rail** to conduct a review with ADAS to determine the scope for improving the accuracy of low adhesion prediction **18** **RSSB** to establish a study into the potential uses of systems on modern rolling stock to: • automatically sample adhesion conditions, e.g. by the controlled braking/release of a single wheel-set on service trains (other than during train braking) • establish the profile, nature and distribution of low adhesion conditions on the national rail network currently and provide input to WSP simulation packages • improve intelligence about adhesion conditions in real time, e.g. use of wireless data transmission to feed details of low adhesion conditions encountered during braking to a monitoring system. The study should take into account operating experience with the Low Adhesion Warning System (LAWS) and consider the lessons learnt in relation to the development of a network wide solution for monitoring low adhesion conditions. The study should be developed in the context of the work currently being undertaken by RSSB in research project T540, 'Scoping and Development of the Adhesion Management System'. The output from this study must include consideration of how the information can be used by the railway industry including the need for signallers and drivers to be made aware of low adhesion conditions in real time
24 The industry should consider what adhesion-improving remedies can be applied to rolling stock that is currently outside the scope of Railway Group Standard GM/RT2461 (e.g. 14X and 153).	Addressed by RAIB Recommendation 11
No equivalent AWG recommendation	**13** **Train operators** to ensure that until RGS GM/RT2461 has been reissued, clauses on sanding are contained within specifications for new rolling stock. TOCS should specify, as a minimum, the requirement for continuous sanding while WSP is active in Brake Step 2 (or equivalent for trains equipped with stepless brake controllers) and above and a sanding rate of 2kg/minute

AWG Recommendation	RAIB Recommendation
No equivalent AWG recommendation	**13** **Train operators** to ensure that until RGS GM/RT2461 has been reissued, clauses on sanding are contained within specifications for new rolling stock. TOCS should specify, as a minimum, the requirement for continuous sanding while WSP is active in Brake Step 2 (or equivalent for trains equipped with stepless brake controllers) and above and a sanding rate of 2kg/minute
No equivalent AWG recommendation	**15** **RSSB** to establish a project to: • measure the accuracy of existing WSP simulation rigs that could be used to support rolling stock approvals. This validation should include reference to records obtained from train data recorders following actual incidents and full-scale testing as appropriate. The latter should include a direct comparison between UIC detergent test data and a simulation of the same... • examine the feasibility of extending the capability of an existing WSP simulation tool in order to predict more accurately the behaviour of an entire train in low adhesion conditions (e.g. allowing for rail head conditioning, the effect of sanding and more than one vehicle). The results from the project should be used to inform the developing Euronorm on WSP equipment testing
No equivalent AWG recommendation	**16** Subject to the successful development of the simulation tool described in Recommendation 15, **RSSB** to undertake a programme of modelling to evaluate the impact of different control strategies for minimising stopping distances under various low adhesion conditions. The simulation should specifically address potential alternative strategies for extreme circumstances including: • Changing WSP control algorithms for the level of slip permitted from the current value of 17-20%. • permitting different levels of slip on wheels on the same train to optimise overall braking during low adhesion conditions. All the simulations should be designed to evaluate the effect of different strategies on braking performance and rail head conditioning and should include simulations with sanding operative. The results from the programme should be shared with those responsible for drafting relevant high-speed and conventional TSIs for possible inclusion in new or revised versions of those documents

AWG Recommendation	RAIB Recommendation
No equivalent AWG recommendation	**17** **RSSB** to initiate a project to evaluate the costs and benefits of equipping multiple units operating over the British mainline network with magnetic track brakes for use in emergencies under low adhesion conditions. The project will: • Address and resolve the outstanding issues identified in Interfleet report ITLR-T17544-001 • Subject to successful resolution of outstanding issues, specify and procure magnetic track brake (MTB) equipment and fit it to a small number of units. The units chosen should represent different traction types with different operating regimes and operate in different geographical areas. • Develop and implement trials of these units, incorporating in-service experience and specific comparative tests with a similar unit not equipped with MTB The project will aim to determine whether MTBs are a cost effective solution for new-build rolling stock and/or retrofitting to existing rolling stock
No equivalent AWG recommendation	**19** **Network Rail** to review ERTMS low adhesion assumptions in the light of the findings of this report and consider whether any changes are needed to ERTMS design or operating parameters in the light of the review.

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

Any enquiries about this publication should be sent to:

RAIB
The Wharf
Stores Road
Derby UK
DE21 4BA

Telephone: 01332 253300
Fax: 01332 253301
Email: enquiries@raib.gov.uk
Website: www.raib.gov.uk