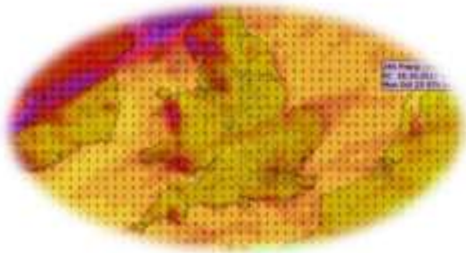
Managing Low Adhesion

Sixth Edition, January 2018

ADHESION WORKING GROUP



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Foreword

Welcome to the sixth edition of the Adhesion Working Group's low adhesion manual. I commend this manual to all as the repository of our corporate knowledge on understanding and managing low adhesion. Although not a 'standard', this manual is our mechanism for documenting and communicating the best practices used in Britain to combat the effects of low adhesion on the mainline railway.

We know that the manual is used by a diverse community to help improve safety and performance during low adhesion conditions, thereby improving customer experience. For example:

- Network Rail's Seasons Delivery Specialists in preparing for autumn;
- Train Operator Driver Standards Managers and Fleet Engineers to inform their training, processes and standards;
- Train Operator and Network Rail Operations Controllers and other front-line staff in responding to low adhesion incidents;
- joint performance teams in Network Rail and the Train Operators who develop and manage performance plans using, for example, delay data;
- suppliers of products, chemicals, and services to the industry, to improve understanding in the supply chain.

This edition of the manual has been brought up-to-date with key findings from investigations and R&D that have taken place since it was last issued in 2013. We have also sought to make the structure more logical and make it more accessible by moving some of the detail into the appendices; rendering the whole in a format that makes it more suitable for modern communication methods like the internet.

Like my predecessors at the helm of AWG, I welcome the enthusiasm of many people from various parts of the industry who have contributed either directly or indirectly to this manual; without whose help the detail and thoroughness would be lacking. I would, in particular, like to thank AWG's editorial sub-group led by Peter McCreery who were responsible for this update.

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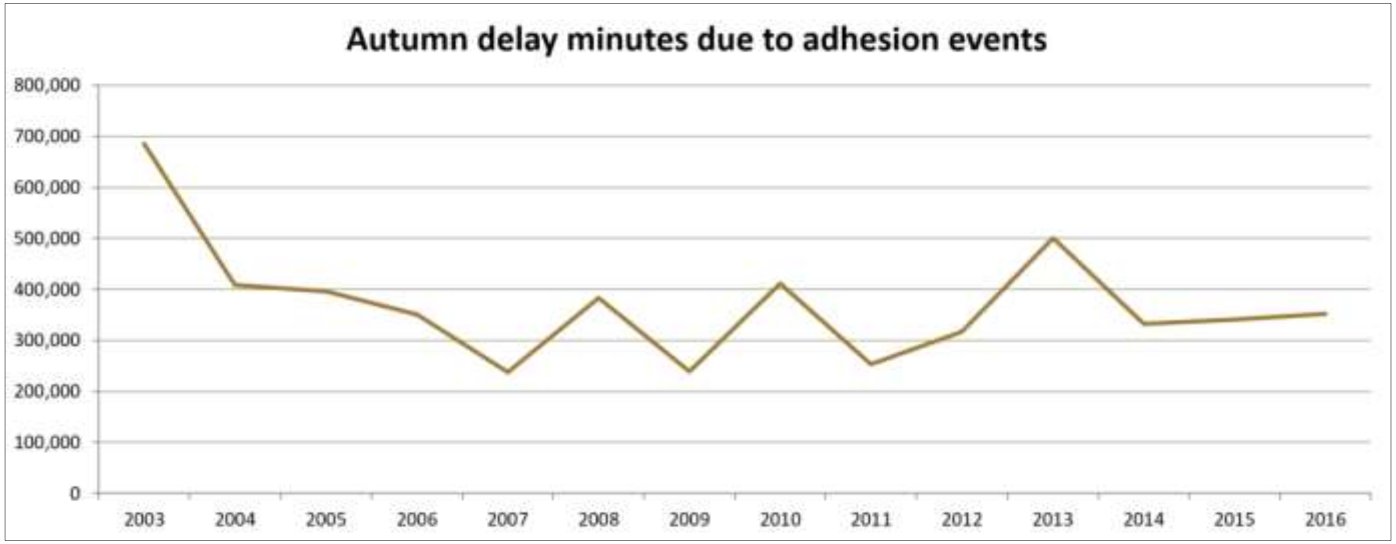
I would also like to pay tribute to all who take time out of their busy day jobs to serve on AWG and to the previous chairs: Mark Hopwood and, before him, Adrian Shooter. Through all their work, the industry continues to recognise the value of the group as a 'centre of knowledge and excellence' for low adhesion.

Notwithstanding the very significant efforts by those at the sharp end of our industry doing their bit to deliver the service in all situations, not just in low adhesion, the achievements of AWG are best demonstrated by the graph below.

There are a number of ways in which we measure the impact of low adhesion, all of which are found in this manual, but perhaps the one that impacts are customers most are the train delays that ensue. Much good work has been accomplished in the past 15 years and the chart below shows how delays due to low adhesion have halved. However, there can be no complacency because we still see bad years such as 2013 and the short leaf fall period still produces disproportionate delays.



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Please take a little time to read through this manual. By understanding the issues and adopting some of the good practice described, hopefully we can all contribute to managing the effects of low adhesion better and help to run a normal timetable safely and punctually during the autumn. Suggestions on how we can improve our management of low adhesion conditions can be submitted to AWG via your AWG representative.

John Edgley
Chair, Adhesion Working Group
Chief Track and Lineside Engineer, Network Rail
January 2018

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About the Adhesion Working Group

The Adhesion Working Group (AWG) a cross-industry focus group formed in 1995 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 key stakeholders.

AWG's remit is to:

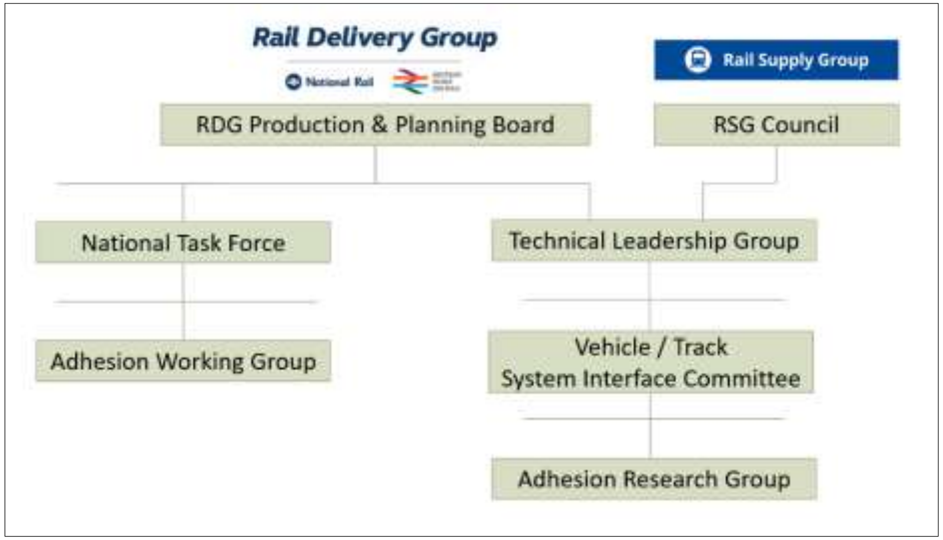
- facilitate industry wide management of adhesion issues in the most effective and efficient way;
- lead the industry in managing safety and performance KPIs associated with low adhesion issues in the most effective and efficient way;
- assist the industry in managing leaf fall related wrong side track circuit failure issues;
- identify and publish best practice methods and techniques for managing adhesion issues (including international best practices and opportunities for international co-operation);
- identify requirements for research into railway operational adhesion issues and help develop business cases to support such research;
- work with other industry bodies to ensure that adhesion issues remain high profile within the industry.

AWG is charted to National Task Force (NTF), and has close links with the industry's strategic Adhesion Research Group (ARG); the industry sponsor for adhesion related research proposals to RSSB. AWG focuses on the more immediate needs of train operators, while longer-term, blue sky research and development is managed by ARG, with appropriate input from AWG.

Stakeholder communication lies at the heart of AWG activities. As well as developing new concepts and processes, the group stimulates the sharing of information through this manual and the 'Right Track' newsletter. Rail industry companies at home or abroad can access this manual online and much of the supporting background material through RSSB's SPARK portal.

AWG's output will be measured by National Task Force (NTF); clear criteria and measures will be developed and agreed for key AWG workstreams and projects. The chair of AWG will regularly report on progress to NTF and will, on behalf of AWG, take their guidance on future direction and focus.

AWG's relationship to other industry groups and its reporting line to NTF can be seen adjacent.



Disclaimer

Throughout this manual there are references and details of products, services and companies relevant to adhesion matters. Any references to these does not imply that AWG endorses the product, service or company, and other products, services and companies may exist offering similar or improved products or services. However, it represents our best knowledge at this point in time (January 2018) which will continue to expand and be reported on as new solutions are developed.

Whilst every effort has been made to ensure the accuracy of this manual, it is published without responsibility on the part of its authors or AWG for loss occasioned to any person or organisation acting or refraining from action as a result of any information which it contains.

No information within this manual should be considered as modifying or replacing legal duties, national standards, operating rules or company policies and procedures.

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1 Introduction

What is low adhesion?

Adhesion describes the 'slipperiness' of the wheel / rail interface. It is measured using a number called the 'coefficient of friction':

- when adhesion is low, the surfaces are slippery – for a plate on a kitchen worktop the adhesion is less than 0.1;
- when adhesion is high, the surfaces are not slippery – for rubber tyres on a good road surface the adhesion is close to 1 which is near perfect.

Adhesion limits the amount of braking or acceleration that can be demanded without the wheel sliding on the rail.

Why is it such a problem to a modern railway?

The railways have been operating with the same basic steel wheel on steel rail interface for over 200 years. This steel on steel interface was adopted not only because of its strength and low wear properties, but also because it offers a low rolling resistance thus reducing considerably the effort required to move heavy loads.

However, this advantage sometimes becomes the railway's Achilles heel, particularly during the autumn leaf fall season. During this time of the year, but not only at this time, the rail surface and the wheel treads can become coated with a range of contaminants. The worst of these are crushed leaves, which, when combined with moisture particularly in the form of dew or condensation, reduces the adhesion level. For a train on dry rails adhesion is typically around 0.25, on wet rails it is around 0.15, but on damp leaf it can be as low as 0.015. Rails with damp leaves significantly constrain the rate of braking. Furthermore, it can also have a profound effect on train performance because low adhesion jeopardises acceleration as well.

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Leaf related problems are not new and have been encountered for decades. Immediately after the demise of steam traction operation in the late 1960s, vegetation control was reduced allowing the lineside to sprout into 'linear forests'. As a result, the low adhesion problems got worse over time and it became necessary to re-instate high levels of lineside vegetation management. However, it is not always possible for the railway to manage all trees as they are not always on railway property.

Further, with the advancement of technology and changing train operation, more demand has been placed on higher adhesion levels to support higher braking rates, shorter yet faster trains and more frequent services.

The nature of the difficulty encountered depends on a vast range of factors which change constantly. The 'adhesion profile' along any stretch of line varies within metres: the temperature and humidity levels can change rapidly; contaminants react differently to the passage of a train; the trains are driven differently; the trains themselves are different; and so on.

Low adhesion occurs all year round, not just in the autumn. Wet rails, accompanied by rail-borne contaminants, can offer low adhesion levels despite the rails looking clean. Analyses have shown as many station overrun incidents due to poor rail conditions can occur outside of the autumn period as during it.

The result of low adhesion is a number of problems:

- reduced ability to stop trains potentially leading to SPADs, station platform overruns and collisions;
- reduced ability to start trains, accelerate and maintain speed leading to lengthened journey times;
- damage to train wheels requiring trains out of service for tyre re-profiling;
- damage to rails requiring regrinding and premature replacement;
- failure to activate track circuits leading to potentially severe consequences.

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What is the safety risk?

The main safety risk from low adhesion arises from incidents and accidents due to trains sliding through stations, open level crossings, passing signals at danger and collisions with other trains or buffer stops. In 2011, RSSB estimated this risk to be between 0.23 and 0.41 Fatalities and Weighted Injuries (FWI) per year. Whilst this risk appears relatively small, the consequences of a low adhesion SPAD for example, could be catastrophic and hence continued management of low adhesion is essential.

What does it cost?

The annual cost of low adhesion to the GB rail industry as a whole has been estimated to exceed £100 million. This arises from many different causes some of which are difficult to quantify:

- SPADS and station overruns;
- performance delay minutes, cancellations and the resulting compensation payments;
- reduced capacity from special leaf fall timetables;
- line side vegetation management and leaf fence maintenance;
- rail head treatment train maintenance and operation;
- repairing rail burns and broken rails;
- wheelset re-profiling or renewal, including transport / transfer / crew costs/ loss of availability;
- sander maintenance and replenishment with sand;
- installing / maintaining train detection equipment;
- rapid response teams;
- staff training and briefing, media and public relations;
- incident investigation and response;
- the cost to staff or customer confidence and bad publicity.


Major winter delays on Piccadilly line caused by Tube bosses 'giving back vital equipment to clear away rotten leaves'

This of course does not include the significant consequences of a serious incident such as a collision or derailment, which could occur as a result of increased braking distances or a failure of a track circuit to detect the presence of a train in a section.

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Unless we radically change the wheel / rail interface, or introduce traction and braking systems that do not rely on it, the laws of physics dictate that the adhesion will remain the limiting factor that governs the ability to accelerate and brake a train. The effects of low adhesion therefore need to be managed in a structured and efficient way, both to maximise the quality and safety of the service, and to minimise the costs to keep the railway competitive.

Successful management of low adhesion requires a 'systems' view of the issue, addressing the constituent parts in an integrated way. This requires co-operation between the different parties: the **people** involved, the **plant** they operate and the **processes** they use. In turn, this co-operation must span the constituent parts of the railway affected by low adhesion: operations, infrastructure, rolling stock and train detection.

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Using this manual

This manual is the repository of corporate knowledge on understanding and managing low adhesion for Britain's mainline railway. Although not a 'standard', it is the mechanism for documenting and communicating the best practices used in Britain to combat the effects of low adhesion on the mainline railway.

As can be seen in the adjacent menu, this manual:

- explains low adhesion in more detail (section 2);
- sets out measures for the management of low adhesion from the perspective of: operations, infrastructure, rolling stock and train detection (sections 3 to 6);
- provides information supporting the main sections (sections 7 to 9);
- provides more detail in the appendices (appendices A1 to A10).

Key recommendations are **highlighted in orange** and summarised in appendix A10. Text in *italics* is quoted from other documents. **Bold** is used for emphasis.

The manual is primarily designed for web browsers. It contains many hyperlinks that navigate to other parts of the manual or content elsewhere on the internet. If reading electronically as a pdf, the manual is best viewed with the 'bookmarks' pane visible as this shows the complete structure of the manual with hyperlinks to each part. If reading in print form, section 9 provides advice on where to find more information.

The detail and experience documented within this manual relates mainly to experience typical of Britain's mainline railway, although the principles of low adhesion management apply everywhere.

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2 Low adhesion

This section of the manual explains what low adhesion is and the background behind the problems associated with it.

2.1 What is low adhesion?

Adhesion on the railway, put in simple terms, is a measure of the grip, or slipperiness, between the wheel and rail. We can measure adhesion levels and a value of adhesion is assigned normally expressed as 'μ' (pronounced 'mew' - a decimal fraction) or sometimes as a percentage.

This μ value is approximately equivalent to the maximum possible rate of deceleration of a given train, when expressed as the percentage of deceleration due to gravity (g). This approximate relationship makes understanding the effects of adhesion on train braking much easier. For example, a modern disc-braked train has a nominal braking rate of about 9%g with a Full-Service brake application. Therefore, when all axles are braking their own weight, we need an adhesion level of at least 0.09 (9%) to support this braking rate without suffering wheel slide during braking. Note that, for simplicity, in the remainder of this manual we shall refer to the adhesion level as a percentage.

For traction purposes however, the adhesion level needs to be higher to start a train without the wheels spinning, ranging from 0.15 (15%) for a typical 4 car multiple unit, up to about 0.25 (25%) for a locomotive hauling a heavy freight train. This depends on a number of factors such as the number of motored axles, the axle loads and the trailing load etc.

In dry weather with clean (shiny) uncontaminated rails, the adhesion level would commonly be found to be between 20% and 40%, in really wet conditions it may be between 10% and 20%. In both of these circumstances braking problems should not normally be encountered. However, adhesion levels lower than that required for Full Service braking are encountered from time to time, particularly in the autumn when moist crushed leaves on the rails can reduce levels to as low as 1%. For those familiar with the 3-Step brake system, this latter value is less than that required to sustain Step-1 braking! However, low adhesion can occur at any time of the year when moisture is present combined with contaminants.

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It should be noted that the spacing between signals is based on Full Service train braking (with an appropriate safety margin added), but braking instructions encourage Drivers to use lower braking rates, applying the brake earlier and possibly lighter at all times and especially when low adhesion is likely or is known to be present.

It is convenient to classify low adhesion into a number of distinct bands as shown in the table below:

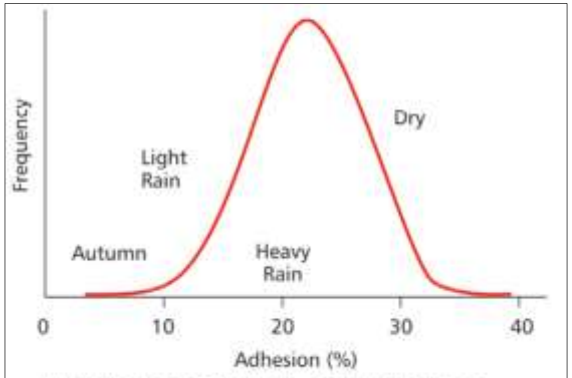
Adhesion Level	Typically	Description
High	>15%	Clean rails wet or dry 
Medium	10-15%	Damp rails with some contamination 
Low	5-9%	Typical autumn mornings due to dew / dampness often combined with light overnight rust 
Exceptionally low	<5%	Severe rail contamination often due to leaves but sometimes other pollution 

It can be seen that modern trains demanding higher rates of deceleration will exceed the available adhesion under certain conditions. This is not too much of a problem for 'typical' autumn mornings as adjustment to the normal driving technique, driving slower and braking earlier / lighter, should compensate for the reduced adhesion by demanding a lower braking rate. These conditions can be compared to driving a road car on a wet road where braking distances will be extended as the tyres cannot grip as well as they can on a dry road.

On the rare occasions when the rails are severely contaminated, such as with dampened leaf contamination, the adhesion level can be extremely low (levels as low as 1% have been recorded) and other measures are necessary to compensate for this such as the application of sand. These conditions can be compared to driving a road car on ice when not only do you need to drive slower but the Council needs to grit the road.

The graph on the right, produced from actual surveys undertaken in the 1990s by the British Rail Tribometer train, shows how frequently the various adhesion levels occur on the railway.

It can be seen that the exceptionally low levels of adhesion (below 5%) are rare as are the very high levels (above 35%). For most of the time the available adhesion levels are well within those required to sustain normal braking and traction power demands.



Low adhesion is infrequent – autumn mornings
Very low adhesion is very infrequent – mostly damp leaf

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2.2 Where does it come from?

Low adhesion arises from a number of causes, most notably from leaf contamination arising from lineside vegetation. Vegetation on the lineside has spread since the demise of track gangs employed to control it during the days of steam locomotive operation. However, it isn't all the fault of leaves on the line, a number of buffer stops collisions have occurred in the past due to rail contamination caused by station well cleaning scattering oil droplets onto the railhead; and damp, light rust following periods of non-use of the track has led to similar incidents.

The following list is by no means exhaustive but identifies some of the more typical causes of low adhesion, which are dealt with further in section 4.3.1:

- crushed leaves rolled on the rails by passing trains activated by moisture;
- general moisture / dampness (dew, condensation, ice etc.) mixed with contaminants on the rail such as rail wear debris or rust;
- the onset of light rain / drizzle after a dry period;
- dusts, particularly coal dust;
- airborne diesel fuel and lubricating oil droplets from diesel trains;
- airborne kerosene near airports and chemicals near industrial sites;
- leaking hydraulic fluid from track machines;
- defective rail mounted flange lubricators.

It can be seen that the causes can be split roughly into those that the railway has little or no direct control over (naturally occurring conditions such as leaves, moisture, rust, ice etc.) and those that are directly under our control ('man made' conditions such as fuel / oil spillages, defective flange lubricators etc.). To an extent, we can also reduce any safety risks to staff and passengers from contamination caused by our neighbours by seeking their co-operation in applying control measures.

The biggest single cause of low adhesion problems is as we all know, are the ‘wrong type of leaves’ crushed onto the railhead by the train’s wheels (under a contact pressure of over 30 tonnes per square inch) to form a hard ‘Teflon’ type coating on the rails. It is known that leaves are drawn into the wheel / rail interface by the aerodynamic effects of passing trains and crushed under the wheels. This hard coating can cause track circuit operating difficulties when it is dry (acting as an electrical insulator) and causes braking difficulties when damp (acting as a lubricator). With very wet conditions, the crushed leaves are softened and then the layer is broken up by the action of passing trains and washed off the rails by the rain. However, it has been shown through testing that the coating can reform after the passage of just a few trains, if the right drying weather conditions are present.

2.3 How is low adhesion 'activated'?

This is one of the least well known subject areas. Setting aside fuel, oil and grease spillages which are obvious lubricators, water (moisture) is the common denominator in low adhesion. Dry leaf contamination or dry rusty rails, will not lead to low adhesion conditions, but add a small amount of water then the contaminant becomes 'activated'. The precise amount of water required is not generally understood, but more water is generally a good thing as it helps to soften the hard leaf-film layer and will wash other contaminants off the railhead. Ice can lead to low adhesion, not because of its surface slipperiness as the wheel / rail contact pressure will melt the ice, but because the melted ice is **water**. Certain atmospheric conditions will result in dew or light rain which will energise these low adhesion conditions (section 3.5).

In 2014, RSSB investigated the effects of moisture on rail adhesion (T1042). This research collated existing knowledge of the effects of moisture on rail adhesion to synthesise an evidence-based definition of 'Wet Rail Phenomenon' and review how mitigations could be improved. An extensive literature search revealed 283 pieces of relevant written evidence, which was then reviewed, and a knowledge map was created. Performance data was also analysed using a variety of sources, including Britain's national autumn performance and weather data from 2010, 2011, and 2012. Key findings were:

The definition of 'Wet Rail Phenomenon'
Poor adhesion conditions caused when low levels of moisture are present at the wheel / rail interface. These conditions are associated with dew on the rail-head, very light rain, misty conditions, and the transition between dry and wet rails at the onset of rain. They are not necessarily associated with the additional presence of other (non-water) railhead contaminants. These conditions are not associated with continuous rain.

- when visible contamination is present on the railhead, it will dominate the adhesion characteristics between the wheel and the rail;
- the most effective way to mitigate against this is the use of properly functioning, on-board sanders, and the treatment of the track by water jetting in conjunction with the application of adhesion modifiers;
- adhesion can be significantly improved by water alone, and that this impact is most significant when the levels of moisture are low;

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- the performance data suggests that colder average air temperatures can significantly influence adhesion performance, possibly due to autumn frosts accelerating greater levels of leaf fall;

Two main scenarios leading to low adhesion events have been suggested although other factors may also contribute:

- a combination of a leaf layer and railhead moisture, often from precipitation, or the environmental changes leading up to precipitation. These events may occur throughout the day, but especially during the afternoon;
- morning dew interacting with contaminants such as oxides or leaves. These account for the high incident rate during peak morning service. Affected mornings tend to be during colder weather. There is a possibility that low adhesion events may be most likely to occur during the drying out of the railhead.

In 2016, RSSB built on the above findings by developing a model to predict the effect of water in the wheel / rail contact patch, and validate this with representative full-scale testing (T1077). This involved tribological testing using the High Pressure Torsion method to assess water effects, and the development / validation of the Water-Induced Low Adhesion Creep force (WILAC) model of low adhesion for varying water / oxide mixtures. Key findings were:

- development of the WILAC model using full-scale test data, which can be used to develop strategies for avoiding and mitigating the impact of low adhesion caused by water;
- laboratory testing provided evidence that low adhesion occurs mainly due to contaminants (e.g. wear debris, iron oxides, leaves) and when the amount of water in the wheel / rail interface is similar to that expected in light drizzle conditions, but over a very small envelope of conditions (for oxide water mixture proportions, surface roughness and third body layer thickness);
- the amount of water on the railhead was dependent on factors other than weather conditions, including temperature and radiation effects.

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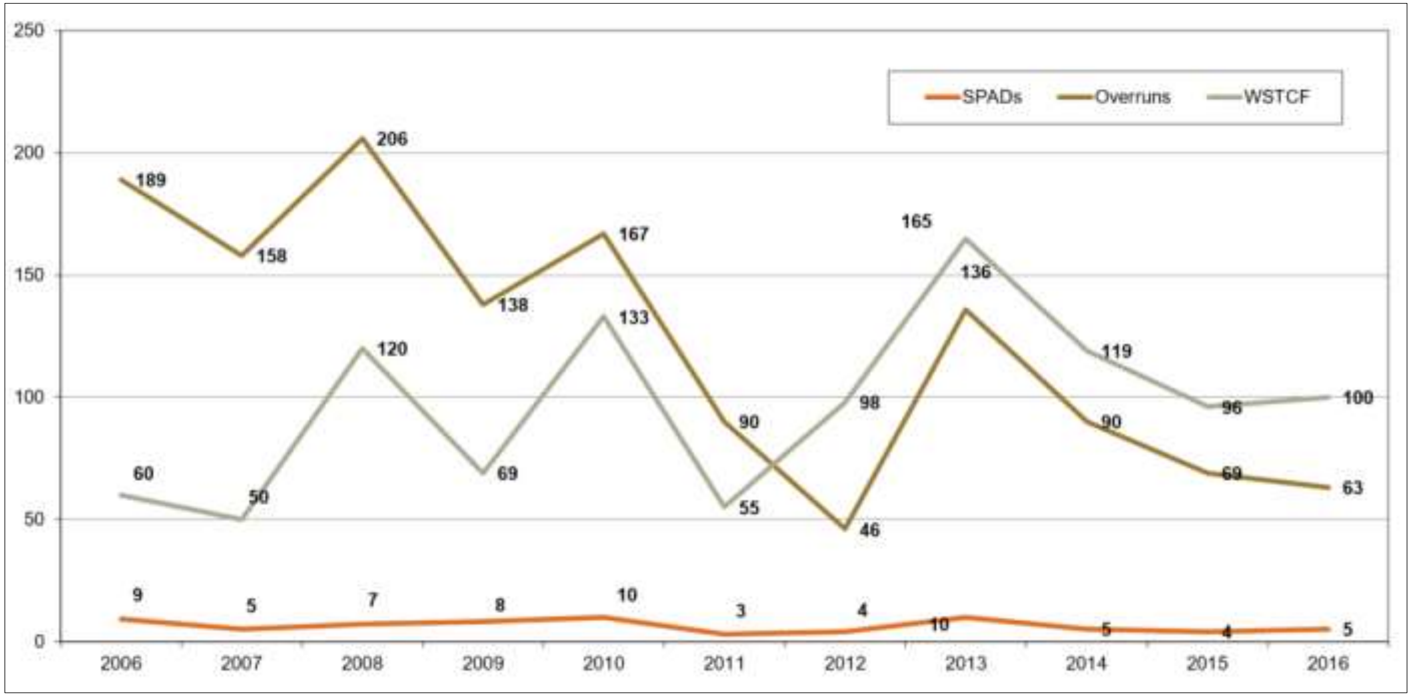
Further insight into the 'Wet Rail Phenomenon' came from a PhD in conjunction with the University of Reading and TRL (Transport Research Laboratory) (COF-TAR-04). Laboratory testing was undertaken to examine how the condition of the railhead (clean vs. contaminated) and its environmental conditions (temperature and humidity) influences the thickness of water film that will form upon it, and how it correlated with friction measurements. Contaminants found on the rail surface were seen to modify the behaviour of water by changing the 'wettability' of the surface, which was also associated with a change in friction behaviour.

2.4 What are the results?

The braking performance of trains in low adhesion conditions continues to be a matter of concern to train operators, to their drivers in particular and, following publicised incidents, to the general public. Low adhesion effects are firstly seen as safety of the line incidents such as platform overruns, Signals Passed at Danger (SPADs) or collisions. The graph below shows the total of safety KPIs over the past ten years.



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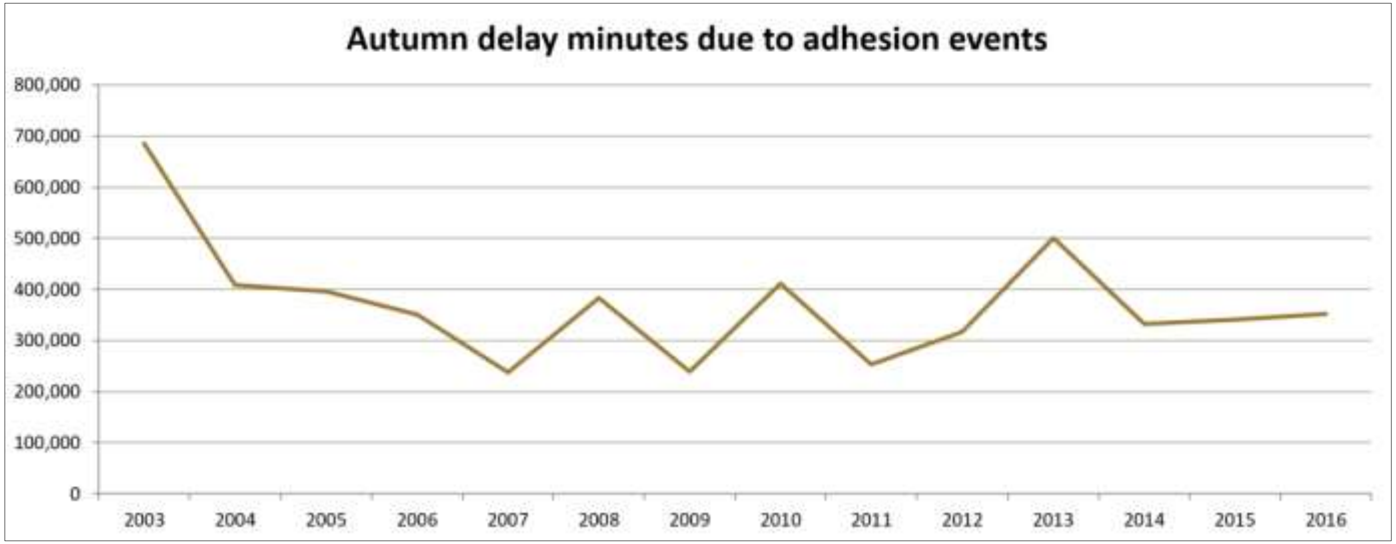
The second major effect is on train performance, particularly the ability to keep to time. Reduced adhesion leads to the driving wheels spinning thus reducing vehicle acceleration and maximum speed, and can even lead to heavy freight trains 'slipping' to a stand on a gradient. This typically occurs when accelerating on rising gradients of 1 in 120 or steeper and when starting away from stations on gradients. Further effects are heard as wheel flats on passing trains, and rail damage can also occur from the wheel flats impacting on the rails and rail burns from slipping wheels during acceleration. The graph below shows the autumn delay minutes accumulated across Britain's mainline network during the past 14 years. In excess of 250,000 delay minutes are typically lost during the months of late October, November and early December. However, the industry's efforts to reduce the impact of delays over time can be seen.



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The approximate split of reported incidents during the leaf fall season is 60% WSTCFs, 37% station overruns and 3% SPADs. However, these are only the direct effects. In addition, there are a host of indirect effects which are to the detriment of the rail industry as a whole. Train service disruption not only costs money but leads to passenger dissatisfaction. Incidents such as SPADs and collisions also cost considerable amounts of money to investigate, and could in the worst case lead to injuries or even fatalities, but just as importantly they erode staff morale and customer confidence.

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2.5 What has been done about it?

The risk to safety and punctuality from low adhesion has resulted in several investigations over the years which have assisted in the identification of: the root causes; the extent of the problem; and, the effectiveness of control measures. The outputs have helped shape the industry's response which is set out in the following sections of this manual.

The analyses were conducted in 1999, 2003, 2005, 2006, 2010, 2013 and 2016 and hence present an historical assessment (appendix A9). The results of the various analyses provide a range of lessons for the whole industry, but **it is emphasised that these are historical analyses not necessarily reflecting current performance or issues**. That said, there are a number of consistent conclusions arising from them which remain relevant today:

- effective autumn response necessitates effective preparation;
- the reviews stressed the importance of an industry strategy to combat autumn, in particular a national railhead treatment programme supported by a national vegetation management strategy;
- preventing the root cause in the first place through vegetation management is the priority; then minimising disruption by implementing measures across each part of the railway: operations, infrastructure, rolling stock and train detection;
- operationally, defensive driving remains the most important means of mitigating the effects of low adhesion supported by experience and training, although there can of course be a price to pay on punctuality;
- train sanders have demonstrated their effectiveness as a trainborne mitigation;
- water jetting combined with Sanditing remains the most effective means of treating affected infrastructure;
- shorter trains are more prone to problems than longer ones;
- wheel contamination has an impact as well as contamination on the railhead;
- conditions vary rapidly along the line because of microclimates;
- the 'wet rail' phenomenon is a significant cause of problems (section 2.3).

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3 Operational measures

Ideally, the effects of low adhesion would be completely countered by technical solutions which either prevented its formation or negated its effects. However, we are some way from this position and must consider the operational, human factors and managerial issues which play a major part in mitigating these effects in the absence of a 'complete cure'.

In the brief overview on low adhesion in section 2 and the more detail appendix A9, it can be seen just how important effective prevention and remedial measures such as vegetation management, water jetting and railhead treatments have become. However, equally important are the 'softer' issues, particularly driving technique when low adhesion is known to exist or can be anticipated, and managing the available information effectively. This section of the manual outlines the important factors that involve the management of operational issues associated with low adhesion.

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3.1 Managing the risk

Railway Industry Standard RIS-8040-TOM "Low Adhesion Between the Wheel and the Rail – Managing the Risk" and its associated Guidance Note GE/GN8540, detail the action to be taken to identify and plan the mitigation of risks due to conditions of low adhesion between the wheel and the rail. It requires the infrastructure manager to have measures in place to control the risk of low adhesion to a level as low as reasonably practical. This includes:

- having processes in place to identify locations where low adhesion may occur;
- publishing details of locations where low adhesion may occur in the Sectional Appendix;
- leading the development of site specific action plans to reduce the likelihood of low adhesion occurring;
- leading the development of action plans to manage low adhesion that occurs at locations not previously known to be affected;
- monitoring the performance and review the plans, at least annually, to ensure that the most effective action is taken.

Train operators are required to co-operate with the infrastructure manager to take action to reduce the risks generated by low adhesion that cannot be eliminated by local treatment at specific sites. In developing the plans consideration is required to be given to providing trainborne systems to improve braking performance under conditions of low adhesion, including:

- optimising wheel slide prevention equipment;
- sanding equipment (as set out in GM/RT2461 "Sanding Equipment").

In addition, consideration must also be given to utilising on-train systems to detect wheel slide activity and alert the driver.

Train operators shall ensure drivers are trained and competent:

- to recognise those locations where conditions of low adhesion may occur;
- on the driving techniques to be used when they become aware of conditions of low adhesion.

3.2 Raising awareness

Raising the awareness of staff, passengers, the general public, media and opinion formers (such as MPs, rail user groups etc.) to the problems created by low adhesion is essential to retain confidence in the rail system. This isn't an easy task but should be tackled on a regular basis to ensure it remains a well understood problem and ensure people know that the problem is being tackled.

3.2.1 Staff awareness

AWG regularly produces awareness and briefing material for publication in the *Right Track* newsletter, published by the Train Accident Risk Group (TARG). This is aimed at all levels of staff recognising that raising and maintaining the awareness of key managers is equally as important as front-line staff and the public. The Red DVD series is another briefing tool aimed at a similar audience.

This newsletter and other material (e.g. this manual) can be used by train operators and infrastructure managers to develop their own targeted briefing and awareness material. Briefings would normally take place ahead of the autumn season and, once the leaf fall season is underway, further briefings should be undertaken or briefing sheets circulated to keep staff advised of progress and performance.

When it comes to staff briefings, experience has shown that joint driver / signaller briefings have an added value in raising the awareness of each other to the duties required and the difficulties experienced. There are also benefits to be gained by reducing the time taken to provide necessary information to the signaller following an incident if both parties are conversant with each other's requirements.

Awareness of emerging problem locations and the likelihood of poor conditions arising requires real-time information on particular trouble spots to be available to drivers. There are many ways of doing this, including information monitors at booking on points, train radio broadcasts (e.g. GSM-R), information in the Late Notice Case, specific verbal briefing by driver managers, etc.

As part of training, train operators should ensure drivers are briefed on low adhesion and the cues to look out for when driving in the autumn.

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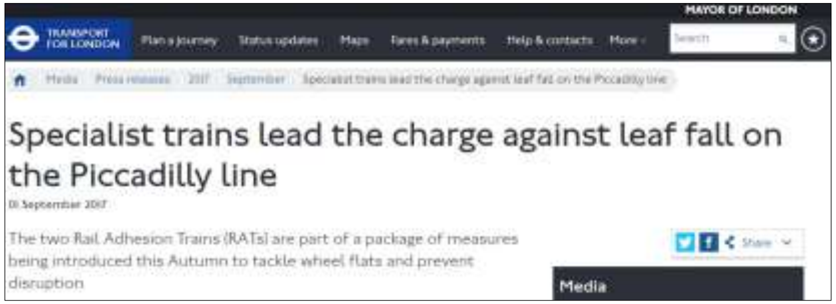
3.2.2 Public relations

Good public relations (PR) are essential to ensure that customers and the general public are educated on the problems faced by rail companies during the autumn. Although some knowledge of 'leaves on the line' is widespread amongst the public at large, it has mostly arisen from uninformed 'bad press' and has become a joking matter in some quarters.

'Meet the Manager' sessions (adjacent) that focus on educating passengers on leaf fall issues / mitigations as well as informing them about leaf fall timetables can be invaluable for this.

The use of web site articles (adjacent), leaflets, posters, and site visits for opinion informers should also be considered.

Planned proactive PR measures will help to minimise complaints by customers and the general public such as from lineside neighbours who may be adversely affected by vegetation control measures.



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Specialist trains lead the charge against leaf fall on the Piccadilly line

The two Rail Adhesion Trains (RATs) are part of a package of measures being introduced this Autumn to tackle wheel flats and prevent disruption

Media

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3.2.3 Media relations

Good media relations are equally essential to ensure that customers and the general public see a balanced account of the autumn problem in the press. As stated above, most public knowledge about the autumn problem has arisen from uninformed, 'bad press' and has become a joking matter in some quarters. This can be improved by press releases, press conferences and ensuring the press receive well-informed information. Appendix A7 contains a template press pack which provides answers to the most commonly asked questions.

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3.3 Training and competence

The competence of key staff undertaking safety critical activities involving rail contamination is of vital importance. This includes activities such as:

- train driving – braking / acceleration technique, operation of trainborne sanders, recognising potential low adhesion conditions, route knowledge of high risk sites, route conducting, etc;
- the reporting of exceptionally low adhesion conditions by drivers, subsequent warnings to other drivers by signallers and conducting test brake stops;
- the identification of low adhesion conditions and high risk sites;
- the implementation and lifting of special operating restrictions;
- the inspection of contaminated rails, including swab sampling, contaminant identification and measurement;
- the inspection of contaminated wheels;
- manual railhead treatment and cleaning processes;
- maintaining and operating sanding, scrubbing, water jetting and railhead treatment equipment;
- the observation of track circuit operation.

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3.3.1 Drivers

Experience has shown that adopting a cautious braking technique and implementing 'defensive driving techniques' can contribute significantly to reducing adhesion-related incidents. It is common practice for train operators to document their professional driving requirements and guidelines within train driving policy documents issued to each driver. Many good examples exist amongst train operators who are usually happy to share these.

Defensive Driving, part and parcel of being a professional driver, has been at the forefront of SPAD management in recent times and is worthy of further mention in relation to adhesion. Key messages are:

- The rolling stock – drivers should know the essentials of the traction and brake type, sander fitment or not, and anything it may be pulling, along with isolated brakes, non-operational equipment and anything else which could otherwise impact on judgement. Additional running brake tests should be carried out to get the feel of the rail.
- The route – drivers should obtain comprehensive route knowledge to encompass those difficult areas, the adhesion black spots, the critical junctions and always be ready to share and discuss such problems with colleagues as a normal part of duties. The Sectional Appendix should be checked for the list of known locations which are likely to be subject to low adhesion. Locations encountered by drivers that are not listed, or exceptional circumstances that apply to listed sites, should be reported. Drivers should also consider the conditions they have seen on their earlier commute to work.
- The situation whilst driving – drivers need to maintain concentration and avoid distraction. They should get to know the danger areas, and make a conscious effort to 'tighten-up' at these times. They should know how and when to conduct a controlled test stop when requested by the signaller. Drivers should also look for changing conditions whilst driving; the cab window is the driver's best friend!

- Braking – with such a variety of traction and trains, different rules often apply but a basic guideline is that drivers should keep an eye on the speedometer and brake gauges and relate distance to approach speed using driving skills to inform judgement. Drivers should apply the braking instructions mandated in their company's driving policy. For some trains this might mean braking earlier and lighter than normal (anticipating twice the normal braking distance depending on conditions) but for other trains it may be best not to brake lighter as it discourages operation of WSP and sanding systems (RAIB report into the station overrun at Stonegate in autumn 2011). Where fitted, WSPs should be allowed to do their job. Drivers should understand the conditions under which the trainborne sander will and will not operate, but not rely on it being there as part of their normal driving technique. Insufficient use of systematic early braking as a strategy was identified as one of the issues exacerbating the poor performance of the Piccadilly line during autumn 2016.
- Maintain distance – when trains are at or near maximum line or train speed, the brakes should be applied before passing a double-yellow (or single yellow on 3-aspect). The speed should then be controlled throughout the braking curve with a target speed of 10-20 mph when approaching the Automatic Warning System (AWS) magnet before the red signal. If the speed seems too high for the train load or rail conditions, then the distance that has been created should be used by a cautious (or defensive) approach to accommodate a good stop. Care is required on the final approach because of the potential for low speed slides. It is better to stop short then draw cautiously up to the red, than to gamble on the last few metres.
- Preparation – drivers need to be particularly cautious and drive accordingly if working the first train of the day, perhaps before the Rail Head Treatment Train (RHTT) has run, or after a period of line closure, or if there are long gaps between trains.
- Non-technical skills – personal, social and thinking skills will enhance the way drivers carry out the above. These skills cover: situational awareness, conscientiousness, communication, decision making and action, co-operation and working with others, workload management, and self-management. More information is available from RSSB.

It has also been shown that the braking performance of certain fleets varies when compared to other similar fleets, even if the same braking step is selected. The number of vehicles in the train also makes a difference to the overall braking performance under low adhesion conditions as the passage of wheels helps to condition the rails. Shorter trains of four or less vehicles are often more susceptible to low adhesion problems (appendix A9). Therefore, drivers should be provided with braking instructions tailored to the fleets they drive rather than just the 'standard' instructions.

Drivers who are inexperienced typically have additional simulator training and are accompanied by a Driver Training Manager on their first run during autumn; those with previous adhesion problems often get more simulator training.

Simulating low adhesion

Often staff are trained in the spring or summer and miss out on the hands-on practical experience during an autumn. Such staff may require additional hands-on instruction and monitoring during the first autumn leaf fall season they experience. Ideally, drivers should have access to simulated low adhesion conditions if training during the autumn cannot be undertaken or poses unacceptable risks. Two methods of simulation are now in common use, the creation of a track 'skid pan' (appendix A2.1.1) or use of train driving cab simulators (appendix A2.1.2). RSSB have issued a Guidance Note GM/GN2643 "Guidance on Wheel / Rail Low Adhesion Simulation" on how to simulate low adhesion conditions for a range of purposes.

Driver working groups

Some operators have found it beneficial to hold 'surgeries' with driving grades or create focus groups to elicit input from those most involved in managing the effects of low adhesion. Drivers facing their first autumn should be particularly encouraged to attend briefings. In one operator, a working group of Driver Managers and Fleet Managers has been set up to manage the autumn season preparation.

Post autumn review

At the end of the season, train operators should establish how well their company performed in respect of adhesion-related incidents compared to previous years:

- which drivers were involved and what was their level of experience?
- what experience of low adhesion did they have, e.g. how many times have they worked an autumn and experienced adhesion related issues?
- had they received specific training and briefing?
- were they pre-warned of the poor conditions?

3.3.2 Signallers

It is equally important that the training and assessment of signallers, incorporates specific modules for managing train operations during the autumn. Signallers need to take action when problems arise with track circuits or when exceptional railhead conditions are advised. This will include requesting controlled test stops and cautioning drivers.

Traditionally, signallers have cautioned drivers by first bringing their train to a stand using a red signal. Not only does this run the safety risk of a SPAD due to low adhesion, it also means the train then has to accelerate on potentially low adhesion track resulting in delays. However, with advances in train radio technology and specifically GSM-R, drivers can now be cautioned on the move. The signaller arranges berth-triggered broadcasts to play a pre-recorded message to the driver when the train enters the affected area, and the signaller clears the signal once the warning has been acknowledged by the driver. **The lower SPAD risk and reduced impact on performance mean that cautioning on the move using GSM-R berth-triggered broadcasts is the recommended method of warning drivers of low adhesion conditions when the signalling system allows.** Berth-triggered broadcasts only work when the Train Describer berths and this is not possible on large parts of the rural network.

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3.3.3 Control office staff

Control office staff should not be overlooked as their input to the successful and safe management of the autumn period is critical. Often such staff will be involved in decision making with regard to implementing and removing restrictions, and may have a plethora of information to hand in which to determine the best course of action. Training on the interpretation of forecasts, the interrogation and interpretation of automatic adhesion warning system outputs, etc. is vital to ensure best use of the information is made. Training is also important on the collation of accurate information so that it may be used post-season for review purposes and planning next season's mitigations.

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3.3.4 Those analysing data recorder evidence

It is generally accepted that on train data recorder evidence provides a broad spectrum of intelligence to the train operator. The ability to analyse and interpret the evidence available from data recorder systems therefore plays an important part in the operator's strategy for managing low adhesion conditions and getting the best out of the intelligence. Train operators should therefore ensure training and ongoing competence of persons who have to analyse data recorder evidence. More information is given in appendix A2.4.3.

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3.4 Timetabling and diagramming

There are a number of steps which can be taken to help minimise the effects of low adhesion by attention to the planned operation of trains:

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3.4.1 Short trains

Experience has shown that it is short trains that are generally more susceptible to low adhesion braking problems (appendix A9). Analysis of adhesion related incidents shows that over 80% of incidents occur with trains comprising of four or less vehicles. As a minimum, drivers should be made aware of the particular vulnerability of short trains. If possible, short trains should be supplemented with additional vehicles thus providing additional wheelsets to help condition the rails and improve overall braking performance.

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3.4.2 Autumn timetable

One way to improve reliability of train services during the autumn is to operate an autumn timetable. Increasing certain point-to-point train running times has several advantages:

- it makes an allowance for a defensive approach to braking;
- it makes an allowance for the train to run at a restricted maximum speed thus reducing the energy required to be absorbed during braking, hence requiring less braking effort and making less demand for higher adhesion levels;
- it reduces the number of delays which can occur following adhesion-related traction and braking problems.

However, it is important that the autumn timetable is properly planned and is not just adding a few minutes here and there: connections need to be maintained; turn-round times must be sufficient; franchise / concession agreement deviations may be required from funders, etc. Most importantly, the timetable alterations must be publicised well in advance, otherwise passengers will turn up for trains that may have already departed.

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3.4.3 Operating restrictions

It may be necessary to implement operating restrictions if adhesion related incidents occur. For example, high risk sites identified as those with the potential for wrong side failures of track circuits should have special working arrangements prepared and acted on (refer to Railway Group Standard RIS-3708-TOM "Arrangements Concerning the Non-Operation of Track Circuits During the Leaf Fall Contamination Period".

Other requirements may include the need to ensure level crossing gates close to high risk sites prone to platform overruns or signals being passed at danger are closed to road traffic prior to a train approaching under significant risk conditions.

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3.5 Managing adhesion information

As technology expands we are faced with ever increasing volumes of data to help us. This data is valuable for identifying when and where low adhesion may be a problem, and for deciding what measures to apply to combat the problem.

3.5.1 Gathering data

Sources of data include:

- **Low adhesion sites** – those sites where vehicles regularly experience problems, which can come from a number of sources such as previous history and local knowledge. An effective way of obtaining real-time reports and post-season analysis of such sites is from automated low adhesion identification / warning systems (section 3.5.6), which can provide a map of such sites together with the severity of the conditions and how the site is changing over time.
- **Weather conditions** – another important piece of information is what the weather is on a particular day and what is being forecast for the next few hours and days. If high risk days can be forecast, then appropriate action can be taken in advance. Leaf fall / adhesion predictions and weather forecasts (section 3.5.4) and real-time data from weather stations (section 3.5.5) also allow us to have up-to-date knowledge of local conditions such as ambient temperature, humidity, wind speed and dew point.
- **Trains** – data can be obtained from train systems (section 3.5.6).
- **Adhesion related incident data** – locations where adhesion related incidents have occurred such as where signals have been passed at danger, stations platforms have been overrun or collisions taken place. Also, locations where trains have failed to be detected by track circuits or where accelerating away from a stand is a problem.
- **Train delay systems** – train delay systems such as TRUST can yield data as to where time is regularly lost in sections during the autumn, thus pointing to sections where adhesion may be a problem. Also, GPS linked with on-train systems can provide very granular levels of detail on low adhesion sites for both braking and accelerating.
- **Vegetation surveys** – data from vegetation surveys can be collected and entered into databases yielding graphical representations of where the poor sites are likely to be. Combining survey data with historical data from systems such as automated low adhesion identification / warning systems (section 3.5.6) can further aid targeting vegetation management.
- **Human input** – further sources of adhesion data can come from human input such as from the drivers, signallers and infrastructure maintainers reporting.

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3.5.2 Disseminating information

Once the data has been obtained and processed into useful information, it is essential that this information is disseminated to those who require it through reliable communication channels. Users include:

- **Train Operators** – to provide details to drivers of where they are likely to encounter problems via information screens, tablets, GSM-R berth-triggered broadcasts, etc.; this needs to be reactive to emerging conditions as well as proactive ahead of the autumn season;
- **Infrastructure Managers / Maintainers** - to plan where vegetation management and remedial measures are required and to react to emerging conditions;
- **Signallers** - to be alert to potential problem sites and implement appropriate operating restrictions;
- **Operations Control Centres** - for overall day-to-day adhesion management;
- **Management** – to maintain their awareness of current conditions.

3.5.3 Adhesion Control Centres

Whilst there are many sources of data as listed above, it is sometimes compiled through a manual process. To assist this, Network Rail often deploys additional staff into Control Offices during the autumn. These may be dedicated control positions manned during the autumn, where all staff have been trained on how to get the best out of the various information systems.

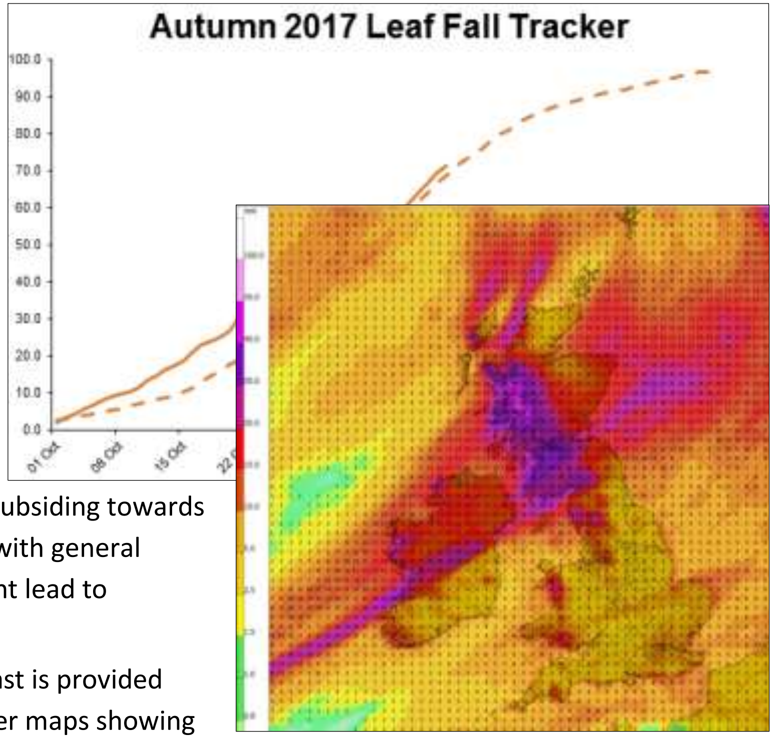
The autumn staff can be dedicated to the day-to-day management of resources employed to deal with adhesion issues. They have access to good information and systems and processes for acting on it, receiving information from a number of systems which give them an accurate knowledge of the current situation on the operating railway. They are able to: direct the treatment trains to water jet the rails and lay treatment; direct the mobile response action teams to locations requiring immediate attention; and, help the controllers plan their daily activities in a more robust manner.

The information is presented in a more automated manner rather than the previous method of manual analysis. With the feedback systems available to them, the controllers are able to monitor train operations shortly after the remedial action has been taken to see if the remedial measures have been successful. From this, weekly performance and operational data can be generated for managers to understand what is happening during the autumn.

In addition, Network Rail's Supply Chain Operations (SCO) operates a 24/7 seasonal control office team to support the delivery of the autumn programme. The control liaises between the seasonal depots, supplier controls and Route controls. They maintain the 'fleet status' through their Fleet Asset Management System (FAMS) and are the first line of reporting for all matters.

3.5.4 Leaf fall forecasting / weather reports

A severe leaf fall period will often start with a hard frost, followed by high winds and then dry weather. The frost and wind cause large amounts of leaves to fall over a short period of time. However, typical seasons are milder with damp mornings, which, whilst less severe, extends the season for a longer period. Heavy rain on the other hand, is beneficial by keeping fallen leaves ‘stuck’ on the ground, and softening crushed leaves and washing them off the rails.



Typically, remedial measures have been deployed between 1 October and 13 December, recognising that there is a north to south graded fall off in leaf fall with the north of the country finishing earliest as temperatures are generally lower.

Leaf fall prediction and weather forecasting services are provided to the rail Industry via the Network Rail Weather Service (NRWS at www.nrws.co.uk), from MetDesk but are also available from companies including The Met Office. Weather forecasts can help to guide us on issues such as when the leaf fall season may begin in earnest, impending risk days and when the risks are subsiding towards the end of the season. Forecasts can also provide us with general weather patterns and approaching events which might lead to significant problems, for example high winds.

During the autumn period, a five-day adhesion forecast is provided containing a summary map of the country with smaller maps showing the long-term outlook. These are colour coded to signify levels of severity, and are uploaded twice per day. In addition, maps are available for each Network Rail Route. Archived maps are accessible.

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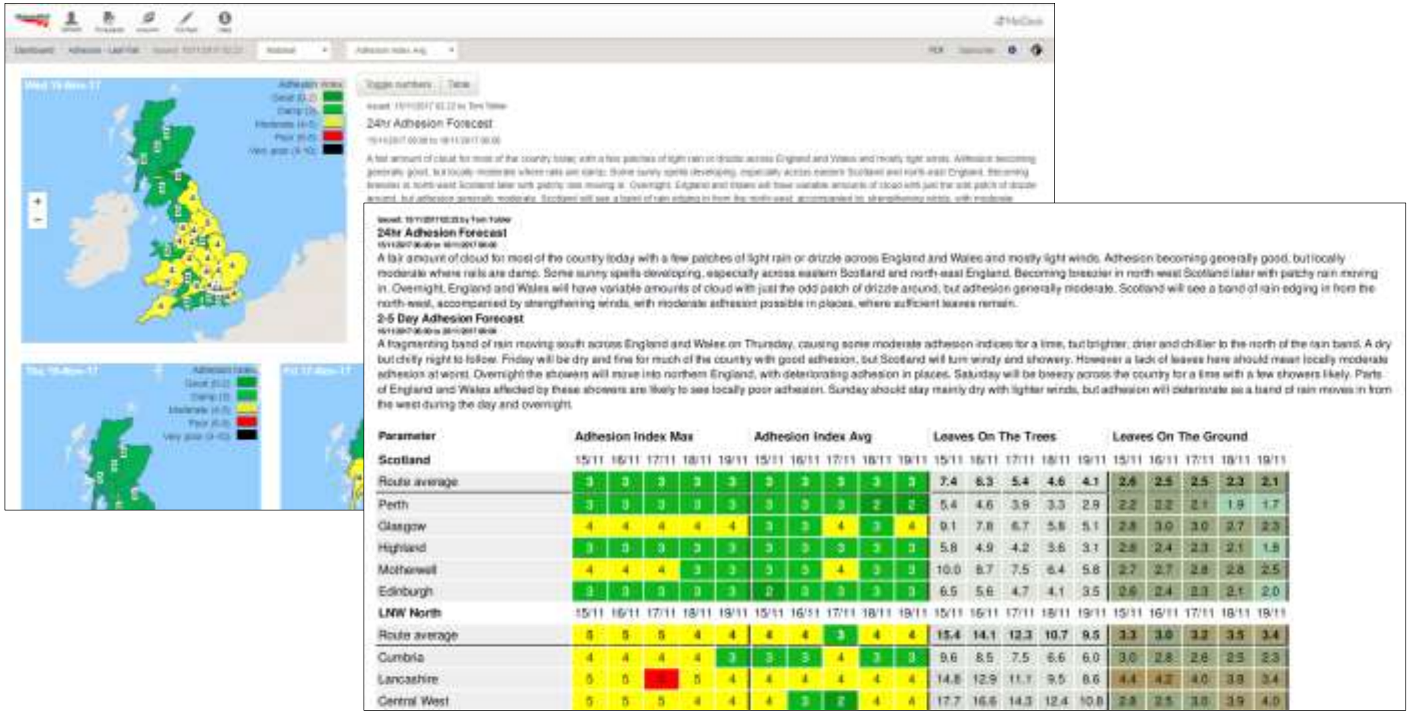
The pictures below show a typical MetDesk national forecast for the autumn. The narrative explains the outlook for predicted adhesion issues on the day and the longer-term outlook.



For each Route specific details for the area can be found, including: a five-day adhesion risk forecast; hourly adhesion risk forecasts for each forecast area and specifically identified high risk sites; the estimated percentage of leaves left on the trees and the percentage of leaves on the ground.

Managing Low Adhesion

The leaf fall risk model produces a risk index which ranges from between 0 and 10. In real terms the index indicates the risk of station overruns, SPADs or wrong side track circuit failures (WSTCFs), brought about through leaf contamination of the railhead. These probabilities are rated from low to very high as shown in the table below.

Autumn Adhesion Index (AAI)	Adhesion Conditions	Probability of Overruns, SPADS & WSTCF	Possible scenarios
0 – 3	Good	Low	Below 2 the risk is low and will be confined mostly to high vegetation index areas (with close or overhanging trees). 3 will be due to moisture.
4 – 5	Moderate	Moderate	The risk is moderate with problems potentially in lower vegetation index areas.
6 – 8	Poor	High	There will potentially be more general problems due to higher leaf fall rates and / or greater leaf litter mobility.
9 - 10	Very poor	Very High	Potentially means general and widespread disruption due to leaf contamination. This situation is most likely to occur during the period around the 50% leaf fall date – normally the peak of the season – when combined with strong or storm force winds.

The NRWS web site offers a daily Network Operations Autumn Daily Report (NOADR) and Network Operations Autumn Cumulative Report (NOACR), which provide key statistics on autumn safety and performance on a route by route basis and can be automatically sent to specific email addresses. Typical examples of an NOADR and NOACR report from 2017 are shown below.

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3.5.5 Weather Stations

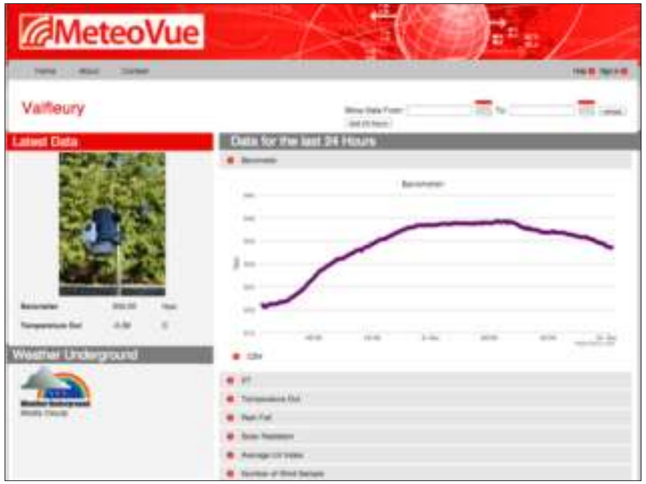
Weather stations can provide an invaluable input to wide area weather / low adhesion prediction systems as well as direct feedback of critical criteria at local hot spots. Network Rail has invested in a network of local weather stations for a variety of purposes.

The system being employed is supplied by MeteoVue, the Series 2, and is a solar powered, battery backed weather station connected by GPRS data. The remote memory unit can store around 20,000 events of 16 parameters, providing up to 6 months of data storage for a 15-minute sampling period. The system is configurable and updateable via a remote server and data can be viewed on a web-based software package.

Typical parameters that can be monitored include:

- Alarm output: provides an alarm when the key trigger factors reach a threshold for likely wet-rail conditions.
- Air-temperature sensor: fundamental measure of importance in all stages of the analysis with potentially wide-ranging impacts.
- Relative humidity sensor: used in conjunction with air and rail surface temperature measurements to determine the likelihood of significant railhead dew formation, and when.
- Dew point: determines when conditions that match the technical definition of dew point are reached.
- Wind speed and direction: used to determine whether dew or frost will form, and even the likelihood of aggravated leaf fall conditions.
- Tipping bucket rain collector: wet-rail conditions are known to occur in certain light rain and drizzly conditions.
- Solar radiation sensor: direct solar radiation can disproportionately increase rail surface temperature in comparison with air temperature, and wet-rail low adhesion conditions are probably unlikely in direct sunlight even at times of the year when the sun is low in the sky.

- Quantum light sensor: this may provide an assessment of ambient light conditions at critical times. Ambient light levels are a function of time of day and weather conditions at the time and may be a factor in rail surface moisture formation and wetness retention (and thus propensity to rust).
- External / rail temperature sensor: used to log temperature data from a sensor located on a dummy rail located adjacent to the running line.
- Leaf wetness sensor: provides direct evidence of whether the rail surface is being exposed to precipitation.



In 2016, a PhD project at the University of Birmingham (COF-TAR-01) developed low cost (<£100) self-contained moisture sensors that successfully identified wet and dry periods under both laboratory and field conditions. Low-cost moisture sensing could therefore be used to communicate data in real-time as part of an adhesion management system. Data from this 'Internet of Things' network of sensors enabled the Met Office to validate their forecasting model, while calibrating it in near real time, to improve the accuracy of forecasts.

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3.5.6 Train-based low adhesion identification / warning systems

An effective way of gaining immediate information on low adhesion conditions is to monitor train wheels slipping or sliding on trains in service and relay these events to a central computer in real-time. The information can then be processed for a number of purposes, including advanced warning to drivers of poor railhead conditions. The information from such systems can also be used in post-season reviews to determine where vegetation control is required prior to the next season.

Three particular systems are worth mentioning:

- Low Adhesion Warning System (LAWS™) – appendix A2.4.1;
- Remote Condition Monitoring systems – appendix A2.4.2;
- On-Train Data Recorders (OTDR) – appendix A2.4.3.

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3.5.7 Identification and marking low adhesion sites

Some of the vulnerable locations identified will be classified as high risk sites either for low adhesion reasons or because of track circuit operating issues. Having determined which sites are high risk and so warrant proactive treatment, these sites need to be brought to the attention of not only the infrastructure maintainer / manager (to plan and implement vegetation management and remedial treatment programmes), but also the train operators (whose drivers needs to be especially cautious at such locations), and signallers (who need to be aware of these locations to implement rules and procedures). High risk sites for low adhesion are required to be published in the appropriate Network Rail Sectional Appendix to aid train operators and their drivers in identifying the problem locations. However:

- The nature of low adhesion is such that new high risk sites may arise during the season. In their bulletin on the platform collision at Darlington in October 2009, RAIB noted the presence of railhead contamination in an area that had not been experienced before, and that it was likely the contaminant had been carried into the area from a location two miles south of the station by earlier trains.
- Equally some existing high risk sites may cease to be a problem. However, because a site is no longer a problem it may not be appropriate to stop addressing it as the improvement could be due to the effectiveness of remedial measures which if taken away may resurrect the problems. The process of publishing details of high risk sites must be dynamic and react to these changes.

To supplement the publication of high risk sites, special lineside signs, can be erected on the approach to them to warn drivers. Railway Group Standard GI/RT7033 “Lineside Signs” provides standard signs for warning of low adhesion sites. Other designs of warning sign have also been used.

Managing Low Adhesion

One extension of this philosophy has been the introduction of illuminated lineside signs, remotely switched on by the signaller or control office staff when low adhesion conditions are known to be present. Known as the Poor Adhesion Display System (PADS™), the system only advises drivers when the conditions are poor, thus reducing the amount of delay when the conditions are alright but unknown to approaching drivers.

Developed by Unipar Services, the PADS™ system allows localised indication of poor railhead conditions by way of high intensity LED displays that are controlled from the signal box. The system comprises two constituent parts: the driver information signs and the signal box control console. Linking each of these devices is a radio communication network which allows information to be passed from one device to another completely automatically and securely, regardless of distance.

When individual warning signs are activated by the signal box, they illuminate and show the simple message 'POOR ADHESION' which flashes at the rate of 80 times per minute. With line of sight, these signs can be seen by approaching high speed trains at a distance of up to 1000 metres even when travelling at speeds well over 100 mph. The positioning of the signs allows the driver enough time to adjust his style of driving **before** the train enters the area of poor railhead condition which is marked by a separate start and termination board.

The communication console is generally kept in the signal box although it can be placed in a control office. Each control console can control up to 32 individual signs and will display the status of every sign via coloured status LEDs. As with all the signs, the control console has its own internal battery backup to allow operation of the system if the mains power fails, generally the battery backup will operate a sign and console for up to three days without mains power. To activate a sign, the operator simply depresses the relevant button for the sign. When the sign has received the message to turn itself on it will send back to the operator an acknowledgement in the form of an audible tone and illumination of an LED status indicator. This process is reversed when the sign is turned off. This enables the operator to have 100% confidence that the system is operating correctly as the built-in fail-safe mechanisms allow intelligent operation of the system's software control.

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3.6 Responding to low adhesion

Even when adhesion information is managed effectively, conditions on the railhead change and may unexpectedly deteriorate. Drivers need to report these situations and signallers play a vital role in advising others. Once these new conditions have been reported, there may be a need to implement mitigations 'on the ground'.

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3.6.1 Managing unexpected railhead conditions

The need to report exceptional (unexpected) low railhead conditions as required in the Rule Book cannot be over-emphasised. This is one of the real-time adhesion warning systems that can be employed to ensure other drivers are warned of the conditions, and allows remedial measures to be promptly taken. Drivers and signallers must be familiar with the requirements of this rule, and implement it in a pragmatic manner. As noted in section 3.3.2, there have been instances where the intention was to stop a train at a signal to warn the driver of exceptionally low adhesion conditions in the vicinity, only for the train to slide by the signal itself! In addition, once stopped, the train can have problems accelerating away again which can lead to further delays.

Rule Book changes have been implemented to reduce the number of occasions that staff are required to go trackside and trains stopped and cautioned regarding low or exceptionally poor railhead conditions. The signaller can arrange for a controlled test stop at 30-minute intervals until the test stop demonstrates conditions are no longer exceptional.

Exceptional railhead conditions are normally considered to be:

- low rail adhesion at a location **not listed** in the Sectional Appendix, or a place where problems were not expected and the conditions are likely to cause difficulties in stopping, or
- exceptionally poor rail adhesion at a location **listed** in the Sectional Appendix, where the conditions are likely to cause more than the anticipated difficulties in stopping.

A typical risk-based approach to managing exceptional railhead conditions must address a wide range of circumstances, for example:

Locations where conditions apply	Action to be taken
Approach to a stop signal	Driver of each approaching train to be told of the circumstances, unless the signal is displaying a proceed aspect
Manned level crossing within the overlap of the signal	Crossing to be closed to road traffic before each train approaches
Automatic Half Barrier level crossing	'Non-stopping' selection will be made where provided
Approach to a platform	Driver of each train booked to call to be advised of the circumstances
Buffer-ended platform	Take the platform out of use, if reasonably practicable to do so

GSM-R train radio provides for discrete warnings to individual trains or general broadcasts to all drivers in an area. The GB Rule Book allows for drivers to be cautioned about poor railhead conditions by non-verbal means. Using a GSM-R berth-triggered broadcast which can be acknowledged by the driver, GSM-R can be used to warn of exceptional low adhesion conditions (when the signalling system allows) without recourse to a verbal radio conversation. This process reduces delays that would otherwise occur if the train was to be stopped for the driver to be verbally warned of the conditions by the signaller.

A complete understanding of the requirements for conducting brake test stops is also needed to ensure the brake test is meaningful and conducted in an appropriate manner. For example, a site incident involving a disc-braked short train should not be tested with a freight train. When advised to make a controlled test stop, the driver should brake the train using the technique that would normally be applied for the prevailing weather and rail conditions at that location, rather than that used for exceptional railhead conditions.

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After the controlled test stop has been made, the driver will normally be required to tell the signaller the result, and whether the railhead conditions should still be considered as exceptional. If the conditions are reported as no longer exceptional, normal working will be resumed, but if the conditions are reported as still being exceptional then the rails will be treated, and another controlled test stop will be carried out. Normal working should not be resumed until a satisfactory controlled test stop has been carried out.

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3.6.2 Reacting to emerging conditions

Once access to information from various sources is available, including predictive reports, it is possible to adjust the response based on the likelihood of low adhesion conditions arising.

By 07:00hrs each morning, Network Rail Routes will provide a weather forecast update based on the adhesion forecast. Typically, the full suite of autumn mitigations will be employed, however when a 'black' day is predicted the extreme weather response process will be utilised. This may include additional: staff; Rail Head Treatment Train runs; and, inspections at high risk sites of low adhesion or of wrong side track circuit failures.

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3.7 Automating the process

The above sections have described a mostly manual process of identifying, predicting and communicating where rail conditions are poor. Changes in driver behaviour have been influenced over recent years through the occurrence of safety of the line incidents, formal driving policies and the continuous targeting of SPAD levels. The industry continues to strive towards introducing technical advancements for the control of low adhesion levels found during the autumn leaf fall.

The technical developments and advancements the industry has embraced, such as trainborne sanders, positively affect the physical adhesion levels available to the train. However, the influence on the available adhesion does not necessarily return conditions back to levels required for normal service braking conditions and thus drivers are normally instructed in 'defensive' techniques to avoid station overruns, passing signals at danger or collisions.

At present we are not able to provide train drivers with real-time information suitable for them to influence their behaviour at targeted locations when driving during the autumn. This is particularly an issue because a high proportion of drivers working for rural, metro and intense commuter operators have less than five year's driving experience, sometimes insufficient to enable them to gain good handling experience of low adhesion conditions. It is also true to say that some of the longer serving drivers have now altered their behaviour through the risk of making a mistake or misjudgement. The advent of on-train systems such as on-train data recorders and their outputs may also have influenced more experienced drivers to change behaviour.

It is now believed that a substantial amount of autumn train delay will be incurred through human behaviour rather than actual physical conditions. Defensive driving, whilst being a cornerstone of safe operation at present, is a performance-inhibiting factor and the driving policies currently in force nationally follow a similar risk adverse theme for trains approaching signals and platforms.

At present, in general, little useful localised rail adhesion information is provided to drivers both in advance of their turn of duty or whilst they are driving. Location conditions and weather conditions can change rapidly, however drivers will continue to drive with a mindset that assumes handling techniques require earlier braking at all times.

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If we're to run a normal timetable, safely in the autumn, then technological solutions are required to be able to "inform" drivers reliably of the conditions they are likely to encounter ahead, on a real-time basis: an Adhesion Management System (AMS). The cornerstone of such a system will be the decision process that determines whether rail conditions are such as to support normal driving techniques or not, a process similar to London Underground's Central Line ACCAT.

3.7.1 ACCAT

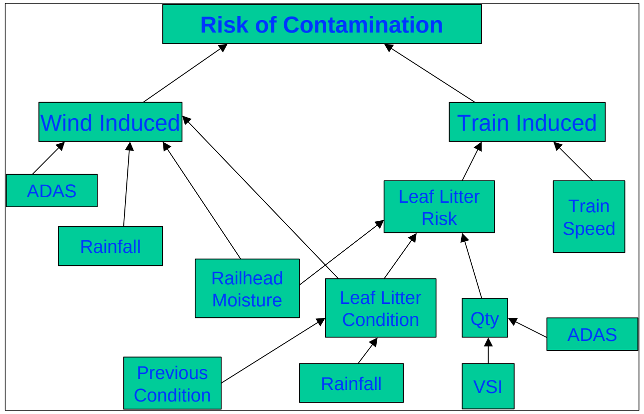
Developed over a number of seasons, ACCAT (Adhesion Controller's Condition Assessment Tool) is used throughout each autumn to determine whether Central Line trains, on the open sections of the Central Line, can operate under Automatic Train Operation (ATO) at the 'normal' ATO brake rate ($0.75 m/s^2$) or whether the reduced ATO brake rate ($0.55 m/s^2$) should be implemented. To deliver the timetable improvements targeted, ATO demands relatively high service braking rates, so it is important to know that these can be sustained when low adhesion conditions are possible. Under adverse conditions, the ACCAT will trigger 'Reduced Brake rate' prompts for defined groups of sites.

The Central line is operated by 85 x 8 car trains of 1992 Tube Stock equipped with 'per axle' WSP. Around 60% of the 74km is in the open and is vulnerable to leaf contamination, particularly at the east end around Woodford and Epping. It is an area of the country where it is also particularly difficult to manage the lineside due to local objectors. This raises particular risks in adverse conditions and has prevented optimum ATO running in the autumn.

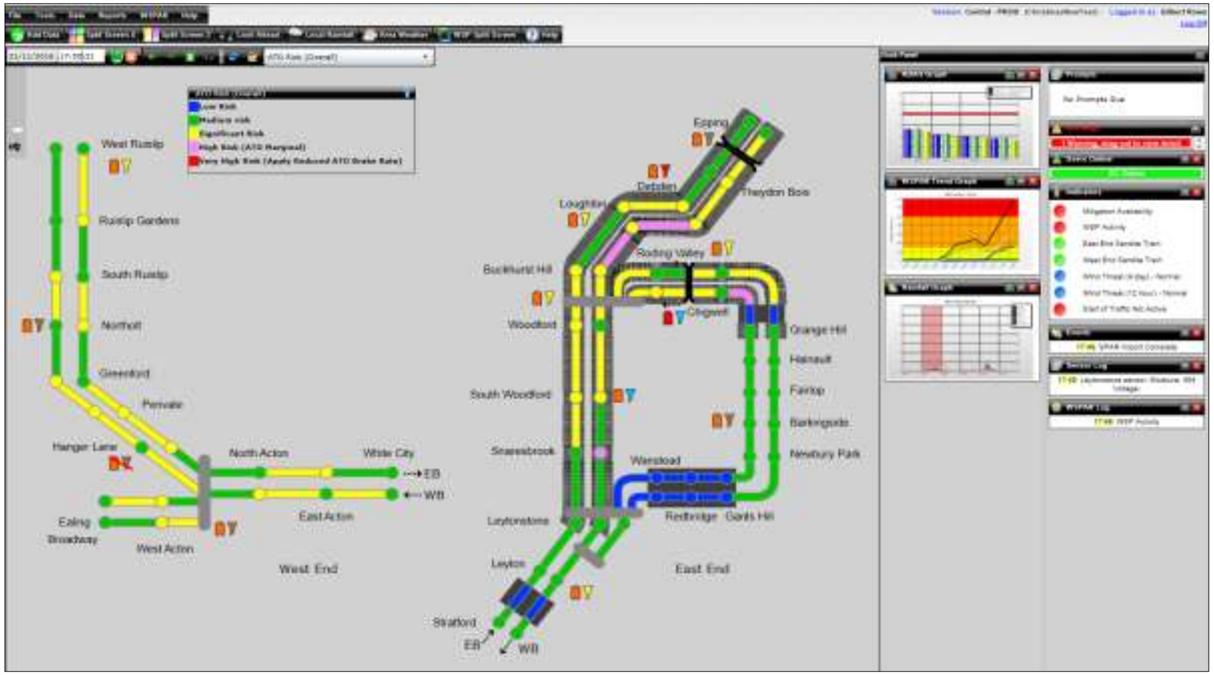
The control measures include lineside vegetation control; running Sandite trains (requiring two trains one for each end of the line to avoid running through the central area); trackside teams who are on leaf fall support duty (which includes hand sanding and feedback on railhead conditions).

Managing Low Adhesion

ACCAT sources a variety of information from various inputs to determine the risk of contamination. This is largely based on leaf fall prediction, rainfall information and moisture presence using railhead moisture sensors. The risk of contamination together with service information and knowledge of current conditions and mitigation actions taken, is used to produce the ACCAT's output.



The 2016 ACCAT screen is shown below. It shows, for each site, the 'ATO Risk' which indicates the likelihood of an adhesion induced incident using five colours. The area with the black highlight around the sites indicates where the reduced ATO brake rate is currently implemented. This is based on the predicted conditions. In the panel to the right, the WSP activity



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graphic can be seen rising which is consistent with deteriorating conditions and vindicates the implementation of the reduced ATO brake rate. ACCAT also has a 'predictive' look-ahead capability to predict what the conditions will be up to 6 hours ahead.

The ACCAT will produce pop up messages to the Adhesion Controller regarding the need (or not) to operate each mitigation train on each path – these are generated, using pre-defined triggers between 75 and 90 minutes before the booked departure time from the depot. Similar pop up prompts regarding ATO brake rate changes are generated and the Adhesion Controller is required to action these without delay. These are also controlled by predefined triggers, one of which (for example) is the identification of the imminent onset of light rain.

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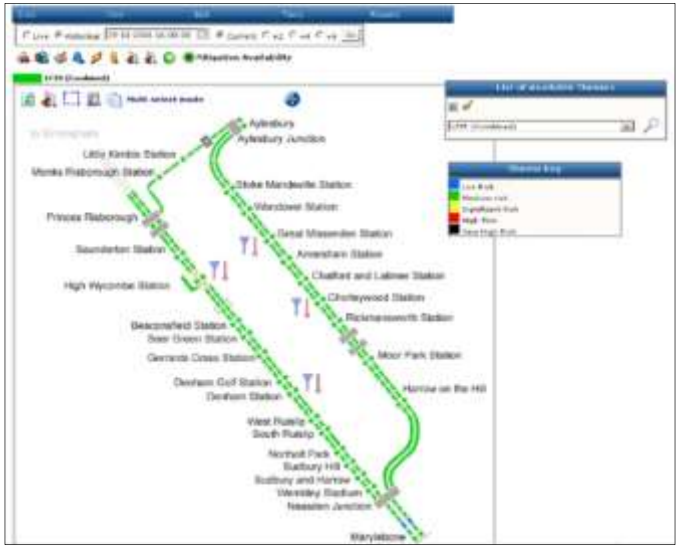
3.7.2 Adhesion Management System



Between 2006 and 2008, AWG undertook a trial of the ACCAT for mainline rail operation working with RSSB. The concept was a tool that could deliver up-to-date information to trains in service, advising the driver when and where defensive driving is necessary, an Adhesion Management System (AMS).

Ideally, the adhesion information would be targeted to those trains needing to know the conditions via a communication platform (e.g. GSM/GSM-R). Only those trains approaching the low adhesion site would be warned and the driver would receive information to say that normal conditions were once again present after passing through the low adhesion site. Once conditions at the site had improved, either naturally or through local treatment, then warnings would no longer be given. Thus, the AMS would help in directing remedial treatments, would reduce signaller workload and would minimise the amount of delay to trains through lack of driver knowledge / confidence in rail conditions.

However, a number of challenges were identified in applying the principle to the mainline and the project was ceased after a few years of test operation.

3.8 Performance monitoring

Performance monitoring should include analysis of safety KPIs (station overruns, wrong-side track circuit failures and SPADs), reports of low adhesion, performance of trains to identify emerging problems and timetable issues. These are key activities to be performed to help guide decision-making and determine where to focus management attention.

A specific output of this process will be a review of the high risk sites. The process for adding and removing sites of low rail adhesion and of wrong-side track circuit failure is detailed in NR/L2/OCS/095 "High Risk Sites for Wrong Side Track Circuit Failures in Leaf Fall Areas and for Low Rail Adhesion". This includes a range of methods which should be considered to limit the impact of these sites on network performance. The effectiveness of these measures should be analysed and changes made as appropriate.

At the end of the season, Network Rail Routes and Train Operators should review their performance in respect of adhesion-related incidents considering:

- was the performance better or worse than the long-term industry average?
- what were the main causes of low adhesion incidents?
- were they management failings, equipment defects and / or operator error?
- which routes, locations and services were most affected?
- what proportion of mitigation trains ran against the booked plan?
- how effective was the autumn timetable (where used)?
- what went well, what did not go well and what should be considered for next season and future years?

These questions need answering each year, so that it is clear where improvements have been achieved and where further improvements are required. Without such monitoring and measuring against industry benchmarks, this is difficult to achieve.

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Each year, Network Rail convenes a 'National Autumn Review' to provide an opportunity to feedback to industry the performance during the autumn. The objectives of the conference are to:

- communicate the importance of Season's Management 24/7 365 days a year;
- provide a forum for best practices to be shared across industry;
- promote learning about current research and development projects that aim to assist autumn preparation in the years ahead;
- learn from other railway administrations;
- provide an opportunity for industry to meet with suppliers;
- outline ongoing and future research being conducted into low adhesion;
- provide a foundation for the future integration of Season's Management skills across all Britain's transport modes.

4 Infrastructure measures

The approach more commonly taken to addressing the infrastructure is to have a long-term vegetation management strategy; putting in place planned, costed and prioritised programmes of work leading to a long-term position of a sustainable, steady state requiring minimal maintenance. To supplement this, a rigorous programme of proactive and reactive processes and railhead treatments are recommended. This section of the manual outlines those low adhesion issues which can be controlled by attention to the railway infrastructure.

A range of measures are available to infrastructure managers and their maintenance teams to complement those undertaken by train operators. The process starts by identifying the locations subject to, or likely to be affected by, adhesion-related problems as outlined in section 3.5 of this manual. Once the vulnerable locations have been identified then the most appropriate treatment can be selected. The appropriate treatments will of course depend on the nature of the contaminant. This should normally consist of measures to eliminate the source of the contamination, such as vegetation management, with a programme of rail treatment where vegetation management alone cannot remove the source of the problem. In general, the most workable solutions can be grouped into three types:

- **preventative methods** – such as reducing the number of leaves at source and preventing leaves from being blown on to the track and drawn into the slipstream of passing trains and into the wheel / rail nip;
- **cleaning methods** – cleaning the railhead to enhance adhesion;
- **friction enhancement** – adding friction improvers such as sand or sand-based products.

Of these, the first is the most effective as it addresses the root cause of the major contributor to our problems, and the latter two keep things moving (or stopping!) by addressing the immediate causes. The following sections summarise the common sources and methods for dealing with them (more detailed information is in appendix A8).

However, to be successful, the efforts put in should be against a clearly defined management process – a plan with structured, funded outputs and robust timescales.

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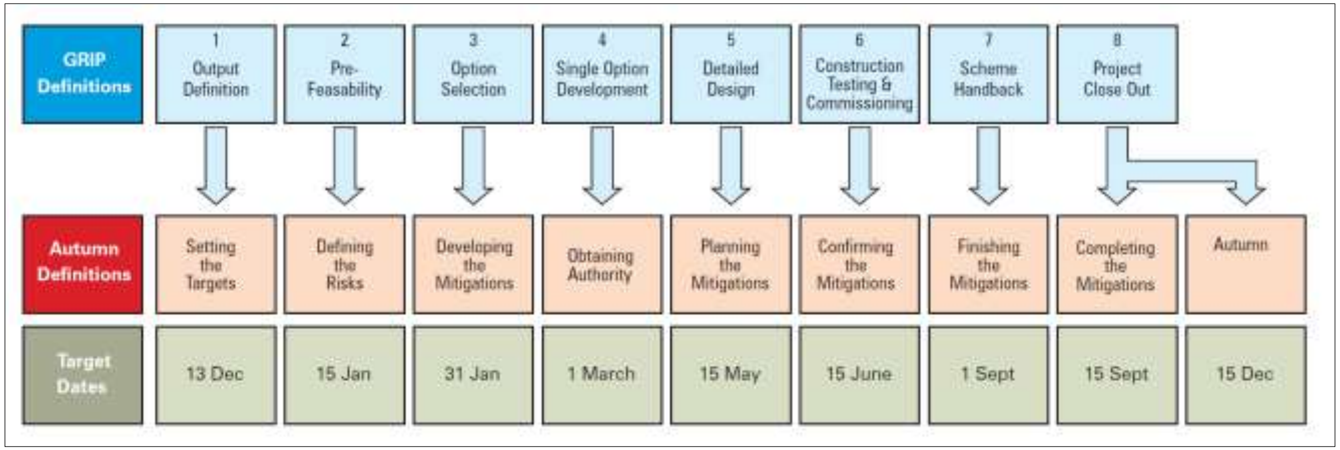
4.1 Autumn management process

Network Rail has implemented a management process for delivering an integrated autumn programme of vegetation management and railhead treatment. The process, laid out in NR/L2/TRK/5201 "Management of Lineside Vegetation", recognises that this must be co-ordinated and planned closely with train operators. The apparently simple relationship between wheel and rail belies a complex series of mechanisms when they become contaminated and experience poor adhesion or poor track circuit detection. The confidence of the driver and signaller in operating safely and professionally in these conditions, and the selection and deployment of counter-measures to eradicate contamination and improve autumn operating conditions is central to success.

The co-ordination of such activities, their logistics and their integration is a significant project. Given the many involved parties and stakeholders - train providers, train operators, signallers, on-track teams – a joint management process is essential.

The 'autumn project' lifecycle

A typical 'autumn project lifecycle' is shown below, being broken down into 8 stages. The overall approach is product-driven not process-driven and each stage is required to deliver an agreed set of products to defined quality criteria. Being an annual cycle, the autumn process can be targeted against specific dates in the calendar.



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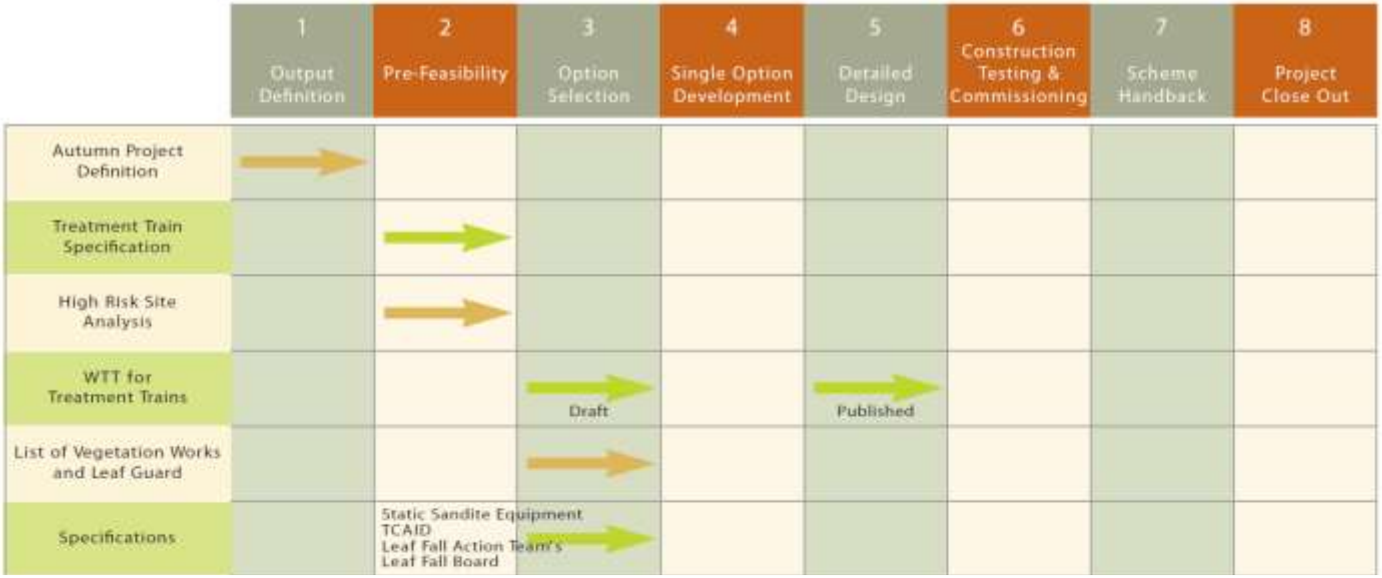
The investment stages within the lifecycle reflect the significant business and technical milestones in the project's development and delivery:

Stage 1	**Target** to be established as the number of 'allowable' delay minutes for autumn. To be established through inputs from the business plan, Route budgets and the Rail Regulator.
Stage 2	Allows the analysis of the previous year's autumn performance, lessons learned and performance data. Looks at possible additional hazards that may affect the coming year's autumn and safety implications. The culmination of this is to produce a hazard / risk register of potential **high risk** sites (adhesion and track circuit risks).
Stage 3	Allows the development of the hazard / risk register into a definition document that outlines all necessary actions required to minimise the effect of leaf fall. It takes into account **possible mitigations** such as draft timings for the treatment trains from the previous year, TGAs, check of proposed vegetation management plans, etc. This culminates in a high level mitigation strategy.
Stage 4	Allows the development of the mitigation strategy to be optimised. A business case to be completed and approval of autumn funding. It allows for finalisation of the **mitigation plan** including risks, assumptions and exclusions (and plans).
Stage 5	Allows for the **detailed planning** of each of the mitigation options available to the Routes, in terms of booking possessions, purchasing equipment and resourcing. Allows the drafting of treatment train circuits and leaf gangs, publications of necessary autumn documentation and the agreement of commercial principles. This should include the finalisation of drop sites for MPVs/RHTTs, etc. Finalisation of WTT (earlier draft timings from previous years included at mitigation plan stage 3 + 2 weeks back). Contingency plans should also be developed in case of treatment train failure, or should planned sites not require treatment, allowing resources to be diverted elsewhere.
Stage 6	Allows for the **confirmation** of each of the finalised treatment train circuits and leaf gangs, publications of necessary autumn documentation, control arrangements and the agreement of commercial issues. Confirmation of leaf gangs, MPV / RHTT trains, WTT, circuits and fleet.

Stage 7	**Completion** of the works on the ground and the production of certificates to demonstrate completion. Train availability confirmed, notices published, control arrangements in finalised form. Allows implementation of on-track activities (e.g. install TGAs) in terms of booking possessions, purchasing equipment and resourcing.
Stage 8	Final **review** of arrangements and readiness, final check of certificates and proof of operation. Operating in autumn, then back to stage 1.

Products

At each stage of the autumn project lifecycle 'products' are required. Wherever possible, guidance on the preparation of the products should be provided and a standard template used. Shown below is a typical product matrix that lists all the products and at which stage in the lifecycle they need to be completed.



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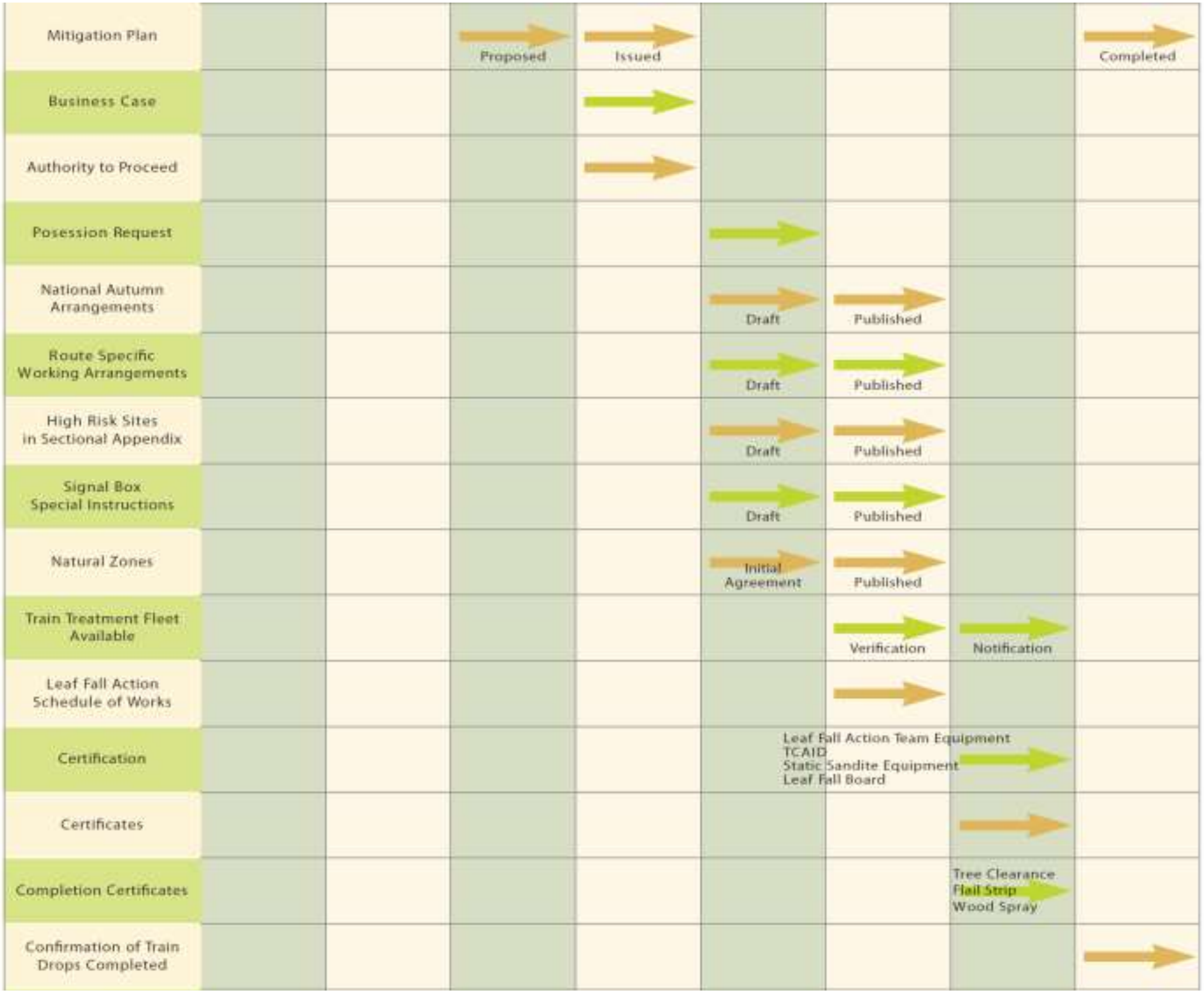

Autumn Planning Daily Phone Conference								
Confirmation of Changes to Train Circuits								

Project Stage Gate Reviews

The purpose of a Stage Gate Review is to confirm that:

- the stage is complete;
- products are signed-off as meeting the quality criteria and are supported by proof of process and consultation;
- any variance from the products stated in the management plan for the stage are understood;
- risks associated with any proposed stage derogation are identified and assessed;
- plans and resources are available for the next stage;
- stakeholders have signed up to the proposals;
- the project is in the business plan.

Stage	Stage Gate Review Date
Stage 1	15 December
Stage 2	15 January
Stage 3	31 January
Stage 4	1 March
Stage 5	15 May
Stage 6	15 June
Stage 7	1 September
Stage 8	15 September

All of the work required to produce, integrate and assess the products should be completed during the stage and prior to the Stage Gate Review meeting. The meeting itself is purely concerned with the formal confirmation of the above points and assessing the risks associated with any variance or derogation. The recommended dates are shown above.

Where actions are needed to resolve outstanding issues arising from the reviews, these should be logged, monitored, escalated, and resolved.

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Progress and overview

The progress of each Route through the stages should be recorded at headquarters level, and be part of the regular monthly review meetings held at executive level in each Route. This will also be the mechanism to escalate issues and ensure closure is being achieved.

Documentation and products will also occasionally be called in for audit by headquarters to ensure that consistency and quality are being maintained.

4.2 Risk assessment

The over-arching Railway Industry Standard for managing low adhesion is RIS-8040-TOM "Low Adhesion between the Wheel and the Rail – Managing the Risk". This standard requires companies to undertake risk assessments and co-operate to ensure low adhesion is safely managed. To meet this requirement, Network Rail developed a risk assessment process to identify and control risks at specific locations, following the model below:

Hierarchy Level	Mitigation
Eliminate (substitute)	Take signalled route of out of use for autumn period.
Reduce	Vegetation clearance; Turn off flange lubricator; Use of tread-braked stock vice disc-braked.
Isolate	Special signal box instructions placing restrictions on certain movements.
Control	Application of water jetting/adhesion modifier (including increase of MPV/RHTT frequency) Traction Gel Applicator; Planned hand sanding at the location; Level crossing equipment fitted with SPAD prediction equipment; All trains fitted with on-train sanders.
Procedures/Protect	Selected trains to perform special running brake tests; Driver briefing.
Discipline	Monitoring and inspection of adhesion sites; Audit of autumn procedures.

All high risk sites are reviewed with the train operators and further enhanced by the risk assessment process. The process is based on an existing 'Signal Assessment Tool', and factors in features such as gradients, level crossings, junctions and train frequency.

4.3 Identifying low adhesion conditions

4.3.1 Common causes

The most common causes of low adhesion are identified below (more detail is in appendix A8):

Leaves

Leaves are of course the predominant cause of low adhesion, and when subject to moist conditions can produce the most extreme of low adhesion conditions. When subject to heavier rain then the leaves get softer and are able to be broken up by the action of the train wheels and washed off by the rain.

Experiments with simulated leaves have shown that as many as 60% of the leaves lying on the track can get swept up by the train's turbulence, being drawn across the railhead and crushed by the passing wheels to form a continuous black thin film around 80 microns thick. The leaf film can become extremely hard when dry such that it is difficult even to scrape off with the blade of a knife.

As can be seen from appendix A5, not all leaves are a problem and selectively combating vegetation will pay dividends by reducing cost and minimising the environmental impact.

One further aspect of leaf contamination is the distance beyond the area of trees where adhesion can still be a problem. It has been shown that the juices squeezed out from leaves, and leaf debris itself, are transferred by the train wheels further along the track in extreme cases, up to half a mile beyond the trees.

A further subset of leaf contamination is from sawdust, which has similar properties to leaves of course. This may be very localised to sawmills, and is unlikely to be a problem where dust collection systems, as required by the law, are working correctly.

During 2007, AEA Technology Rail completed research for RSSB looking into the characteristics of railhead contamination to improve the industry's understanding of how leaf contamination bonds to the railhead (T354). The objectives were to:

- identify the binding agent that causes crushed railhead leaf contamination to adhere to the rail;
- identify, based on knowledge of the binding agent, products and processes that may be safely used in the rail environment to enhance current railhead treatment processes;
- provide an improved understanding of the properties of leaf contamination to enable monitoring and management of low adhesion conditions.

The leaf films that were analysed were artificially created using real leaves crushed onto real rail on a full-scale wheel-on-rail rig. The rig reproduces full sized wheel-rail contact, and slip can be introduced between the surfaces to simulate braking / traction.

The investigation of molecular bonding to determine the binding agents required the application of sophisticated analysis methods so AEA Technology Rail commissioned Newcastle University to lead this part of the work.

The chemical nature of rail steel is well understood, so this offered a good starting point for understanding how the highly complex mixture of leaf molecules bonds to the rail surface. The surface of the rail steel is essentially iron oxides, and these iron oxides can interact with other ionic species through electrostatic interaction such as ionic bonds, hydrogen bonds and Van der Waals forces. This project explored if the leaf film is bonded to the railhead through such interactions by using a range of physical analysis techniques. The analysis of leaf films resulted in the following conclusions:

- analysis of the three different leaf types (Horse Chestnut, Sycamore and Oak) validated the technique of leaf film creation using the full-scale wheel on rail rig;

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- The in-depth analysis of the leaf film provided knowledge of the functional groups present. Based on the functional groups present, the binding agent within the leaf film is believed to be lignin (along with cellulose, and pectin). Other constituents contributing to the adherence of leaf to the rail include phenolic compounds, polymerised fatty acids, other organic acids and inorganic metal ions;
- The proposed hypothesis suggested a mechanism for the low adhesion between the top side of the leaf film and wheel. The cellulosic material within the leaf film absorbs water from the surroundings and retains it. Under the action of large wheel load this water is expelled out providing fluid lubrication and resulting in low adhesion. This explains why presence of mist or light rain is necessary for producing low adhesion.

It was observed that some of the bonds form only within a specific pH range, which provides an opportunity to weaken the bond and to enhance the existing methods of leaf film removal.

In 2015, RSSB conducted a knowledge search (S235) to identify what research has been published or, underway, on the biochemistry of leaf contaminated films on railheads. Five main research institutions were identified as leaders in the field, wherein some research centres have developed and tested models on leaf contaminated railhead films, identified the main binding agents and pH conditions, or iron oxide layers. The main binding agents and interacting forces present in leaf railhead bonding have been identified as: electrostatic forces, ionic bonds, van der Waals forces, hydrogen bonds, lignin, cellulose, pectin / pectin gel, cutin / cuticular wax, and pyrite. Useful insight has also been gained into the chemistry of iron oxide layers:

- a new multi-layer model that illustrates when leaves are crushed by passing trains on the tracks, the leaf film that is formed on the railheads has a slippery layer and a chemically reacted surface layer;
- a tarnished layer on the railhead is created by a chemical reaction which is distinctly different from other types of layers. This layer is much softer and is found to significantly reduce friction;
- two distinct types of iron oxides were found to have formed on the surfaces: α-Fe_2O_3 (hematite) and Fe_3O_4 (magnetite). The hard hematite was responsible for the abrupt increase in adhesion under both wet and dry conditions, while the softer magnetite was attributed to suppressing the increase in the adhesion.

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Rain / Moisture

Heavy rain is often an ally as it tends to wash contaminants off the rails. It also helps to keep fallen leaves on the ground and prevents the turbulence of passing trains from lifting them onto the railhead. The presence of reasonable amounts of water would not normally reduce adhesion levels below that required for normal train operation.

However, small amounts of water are the most common catalyst for low adhesion such as very light drizzle, dew, high humidity or misty conditions, condensation forming on the rails or when the rails are drying after rain. These are the times when low adhesion conditions are most likely to arise. If this is combined with overnight rust on the rails or, worse still, crushed leaves, then the conditions may become exceptional. The effects of this are normally short-term but can become more prevalent where drying out is more of a problem such as in cuttings.

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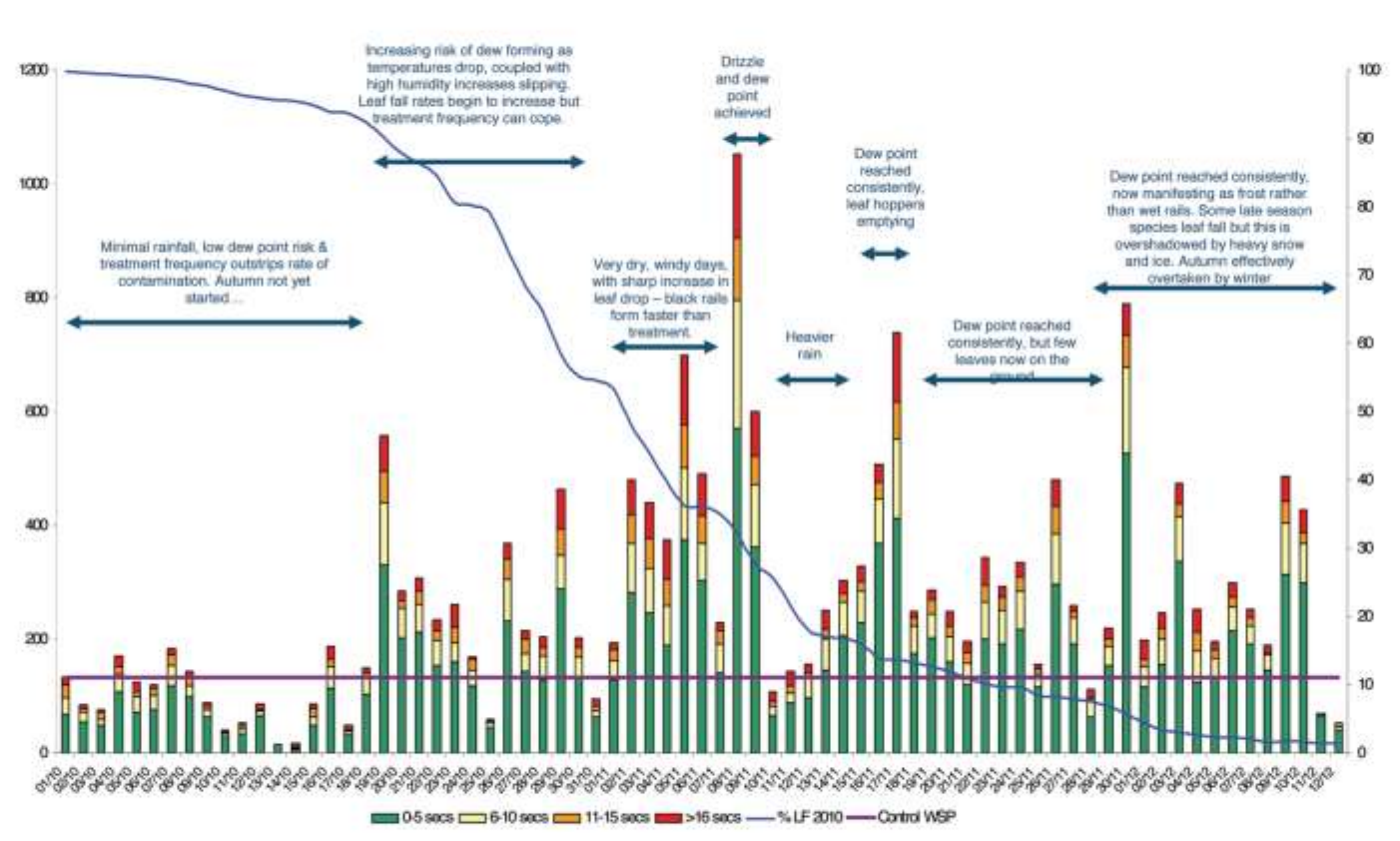
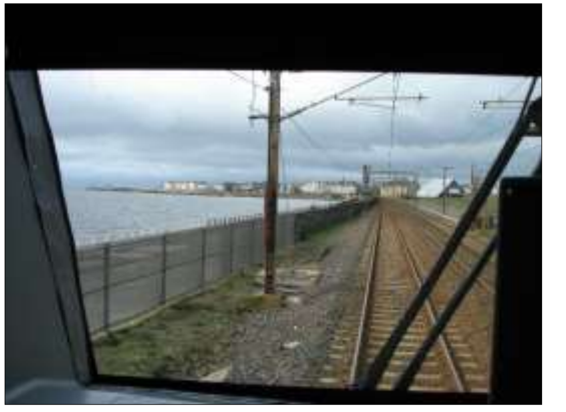
The chart below correlates the amount of wheel slide experienced by trains (in seconds) to factors that lead to the rails being wet during a leaf fall season.



Sea Spray / Salt



Other locations where small amounts of water may arise are along coastal routes where sea spray may be a problem, close to industrial complexes such as cooling towers, or agricultural processes such as crop spraying. Although not proven, there is anecdotal evidence that salt from dried out sea spray will absorb moisture and accelerate rail surface rusting leading to reduced adhesion levels when combined with moisture.

Ice / Snow

The effects described above caused by small amounts of water or moisture can also arise when ice or snow on the rails is melted by the passage of train wheels leaving a moist railhead behind it.

Rust

Although shiny rails appear clean, they invariably will have a light coating of iron oxide and hydrated iron oxides (rust). This particulate rust also has the ability to ‘mop up’ oils by absorption. The most significant effect of rust is when combined with small amounts of water.

Oily Matter

Oil is the next most common catalyst for low adhesion after moisture. Oil can come from a variety of sources such as drips from locomotives and diesel multiple units (fuel oil and lubricating oil), spillages from track machines (hydraulic oil), badly aligned flange lubricators (grease), near airports (aviation fuel), etc. Specific locations may become particularly affected such as where locomotives regularly stand at a signal. Train wheels act to spread oil deposits thinly and along the railhead increasing the area affected.

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Solid particulates

Certain solid materials in the form of particulates can become a problem particularly when subject to moisture. Examples of this are coal dust and small coal fragments forming a slurry on the railhead at locations where coal trains load and unload, and clay / cement where these are loaded / unloaded. Similarly, iron ore pellets have been known to cause the same effects as moist rust on the railhead.

A reminder of the risk of contamination

In their report into the collision at Exeter St Davids station in January 2010, RAIB highlighted the risk of contamination from road vehicles where they cross the railway at level crossings. While it is not clear whether this has any bearing on the incident, road vehicles can bring mud, oil, water and other deposits onto the railway. This will have significance whether there is a need to stop trains beyond the crossing.

4.3.2 Recognising contamination

Unless we know what form of contaminant is present, we cannot determine the most appropriate method of treatment. It is therefore essential that persons examining rails for contamination know what they are looking for. This requires knowledge of the potential causes of low adhesion, the sources of them, recognition of physical characteristics and understanding the appropriate treatment.

Some forms of contamination are immediately visible, e.g. crushed leaves and rust, whilst other forms cannot be seen by the naked eye, e.g. chemical pollutants, thin films and oily matter. Just because there's no obvious contamination doesn't mean there's none present! It may be necessary to use supporting techniques to identify the presence of contamination. In some cases, particularly after an incident where adhesion is a factor or where recurring problems arise without adequate explanation, it may be necessary to take samples from the rail using swabs.

4.3.3 Taking swab samples

Swab samples can be scientifically analysed in a laboratory to identify the contaminants present. Portable sampling kits are available to allow on-site data collection to improve determination of railhead contaminants. The kit enables material of the following types to be collected:

- fine solids or small quantities of liquid;
- larger samples of solid material;
- liquid samples.

Care must be exercised when taking samples to ensure that only the running band of the rail is sampled as there will be gross amounts of rust (often oil soaked) on the shoulders of the railhead. Also, contamination from other sources, such as grease on hands, should be kept away from the sample.

Swabs for solid particulates are a grade 541 filter paper. Liquid samples are obtained using a Pasteur pipette and placed into glass bottles provided in the kit. It has been found that in many cases the use of surface replicating tape provides information as good as, if not better than, and can be gained through a photograph. The surface debris picked up may also be examined under a microscope for further evidence.

As a guide, where it is alleged that a train has been unable to stop because of low adhesion on the railhead, samples should be taken from both rails, starting from a point as close as practicable in advance of where the train stopped, then progressively at intervals of 100 metres back to a point as close as practicable in advance of where the driver reported low adhesion. Typically, between 10 and 20 samples may need to be taken.

However, swab sampling doesn't yield immediate results and any moisture will not be present by the time the samples arrive at the laboratory. Further information on taking swabs samples for analysis may be obtained from Socotec.

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4.3.4 Measuring adhesion levels

Sometimes it is necessary to measure railhead friction levels, for example after an operating incident or for testing and development purposes. There are a range of measuring tools and techniques which vary in their levels of accuracy. RSSB guidance note GM/GN2642 "Guidance on Wheel / Rail Low Adhesion Measurement" provides details on the range of measurement techniques, and the advantages and disadvantages of each. Table 1 of the guidance note recommends differing solutions depending on the requirement for measurement.

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4.3.5 Measuring contamination

Following a SPAD, station overrun, near miss or collision, the Infrastructure Manager should investigate the circumstances leading up to the incident. This should include assessing the current condition of the railhead and train wheels, if low adhesion is thought to have been a contributing factor. To aid in this process, hand held devices are available, known as an 'Eddy Current Device' (ECD). The ECD can also be used to monitor the general condition of the railhead throughout the year.

The 'Sonatest Easy F' is one type of ECD which has been used in the past. It can be used to measure coating thicknesses on ferrous materials, e.g. paint thicknesses, and is considered suitable for accurately measuring the thickness of contamination on the railhead. The ECD can be used to collect data showing the level of contamination on the railhead to:

- monitor the performance of MPV treatments;
- monitor the performance of RHTT treatments;
- take general readings of levels of railhead contamination.

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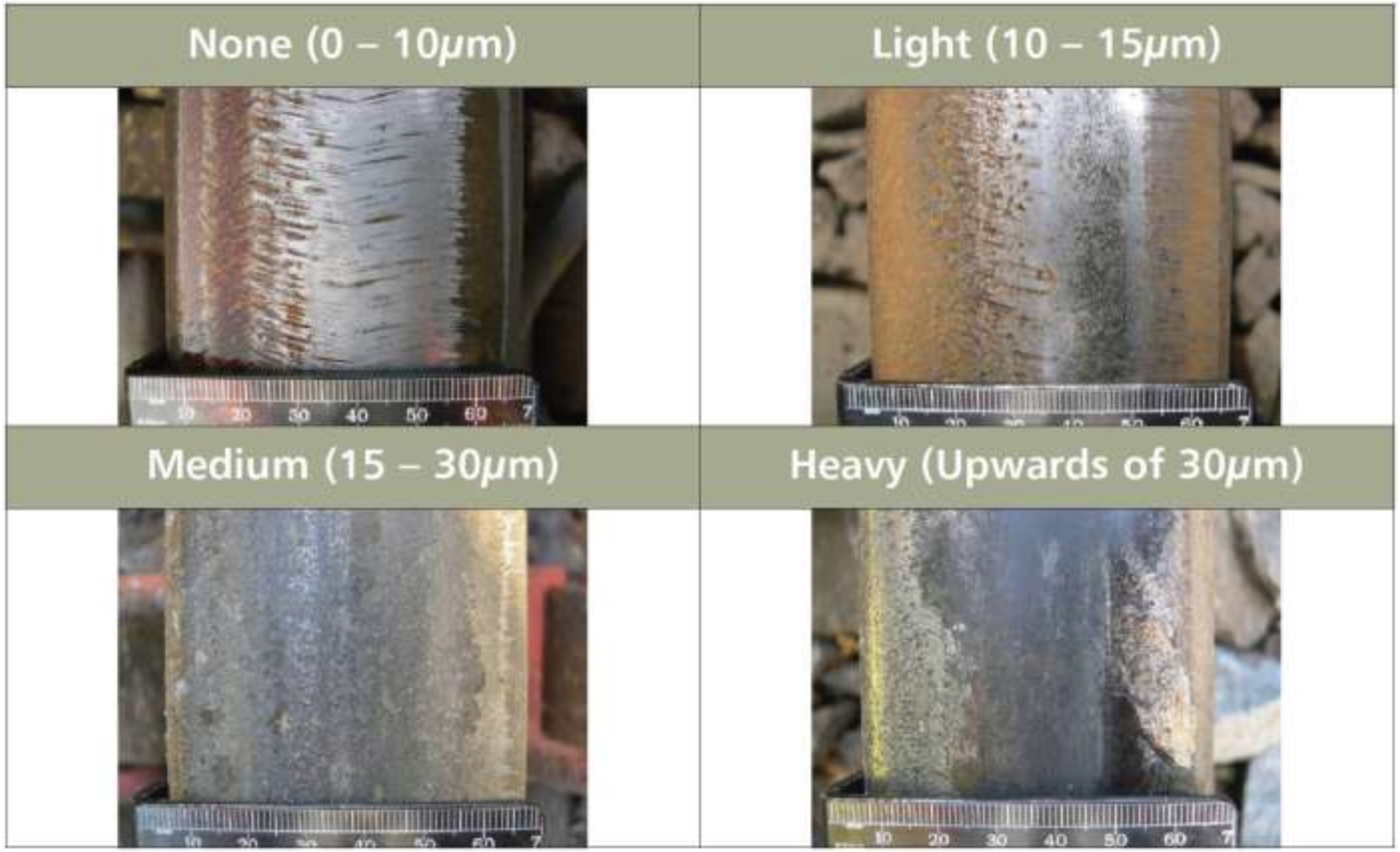
For general recording of railhead conditions, it is recommended that a minimum of five readings are taken at three separate locations. Ideally, where time and track safety considerations allow, these reading should be spaced out as five readings ten paces apart along a section of rail. Readings are taken within the visible running band on the railhead, making sure that the ECD is held at 90 degrees to the railhead surface.



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4.4 Preventing the contamination

As already noted, the best method of dealing with potential high risk sites is to remove the source of the problem or prevent the source from getting onto the railhead. It is now clear that vegetation, if left unchecked, will become an increasing problem year-on-year. It is usually not possible to complete all that is required in one year, and sites that are not a problem now may become a problem in just a few years' time. As stated in the introduction, low adhesion has only become a serious problem since the demise of steam locomotive operation around 50 years ago. It is therefore paramount that a sustainable lineside management strategy is adopted as the trees generally have many years of growth left. The size of the vegetation canopy is growing and the cut back of vegetation should exceed the rate of growth in the problematic locations.

Failure to adequately control lineside vegetation was identified as the main cause of poor performance of the Piccadilly line during autumn 2016. Tree growth and a reduction of tree control in 2015 and in 2016 allowed leaves to grow in large amounts. Together with a combination of rain, temperature, high wind gusts and leaf maturity, this caused leaves to fall in sufficiently large quantities to reduce adhesion to a level low enough to cause substantial wheel damage.

4.4.1 Vegetation Management

Effective vegetation management has become one of the main planks in the defence against low adhesion. It is easy to understand why this should be, as removal or control of the main source material (leaves) removes the source of the worst kind of contamination. However, indiscriminate removal of lineside vegetation is both environmentally unfriendly and unnecessarily costly. It is not always possible to remove all problem trees as many are not on railway land but on neighbouring property and permission to address these will not always be forthcoming. Neither will it always be practicable in any case. Lineside vegetation not only poses a hazard to train operation through low adhesion, but also poses other hazards including:

- obscuring drivers' view of signals and lineside signs;
- a danger to people on or about the trackside by obstructing positions of safety or reducing clearances;
- preventing proper inspection of assets;
- damage to assets such as drainage systems.

Vegetation management is an environmentally-sensitive issue and should be undertaken in accordance with laid down procedures. The policy adopted by Network Rail is one of '*maintaining its line sides in a professional and sympathetic manner and to work as far as practicable in harmony with the natural processes in the environment'.*

Consideration should also be given to Sites of Special Scientific Interest (SSSI) as these are protected by law and require special attention. Further advice may be obtained from the Forestry Commission.

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The programme for vegetation management should be an all-year-round task and not a fire fighting exercise immediately before the leaf fall season. Vegetation control is effected more readily between the leaf fall season and the end of winter whilst the problem trees are naturally bare of leaves. Not only is cutting easier, but the impact on the railway's neighbours is lessened as the natural obscuration afforded by vegetation is generally not present.

There are also constraints to consider on vegetation control during the 'bird nesting' season which also makes lopping / felling activities more difficult. The bird nesting season is not set in stone but considered to start in March and end in July, depending on the species of bird, location of nests and weather conditions. Destroying nests, eggs or fledglings, etc. is an offence carrying hefty penalties and possible imprisonment. During this period a precautionary approach should be taken and checks for nesting birds should always be undertaken.

As already discussed, a plan encompassing a 'sustainable lineside management package' should be constructed, that will provide long-term benefits to the railway, the environment, wildlife and railway neighbours. However, there will always be cases where the requirements conflict, at which point the safety of the railway must always come first. The plan should not only look at the high risk sites, but should also take account of other sites that may develop into high risk sites at some point in the future. By addressing these sites early, more intensive work will be avoided at a later date. It may even be possible to form alliances with local companies to recycle vegetation or use it in wood burning power plants.

Tree type is an important factor as certain types cause significant problems (Sycamore, Horse Chestnut, Sweet Chestnut, Ash, Poplar and Common Lime), whilst some are less troublesome (Oak and Beech), and others cause very few problems (Hawthorn). Specialist help from qualified tree management consultants may be required if such expertise is not available in house. The 'Troublesome Tree Chart' in appendix A4 provides further details of tree types and their likely effects, while appendix A3 and appendix A5 provide further guidance on vegetation management.

It should always be borne in mind that mature trees contain large volumes of water extracted from the ground, and wholesale removal of trees has the potential to create drainage and stability issues. Ground works may be necessary to compensate for this.

Network Rail and their contractors use a variety of methods to clear the lineside of vegetation including power cutting equipment mounted on Road Rail Vehicles (RRVs). More detail is given in appendix A2.2.1.

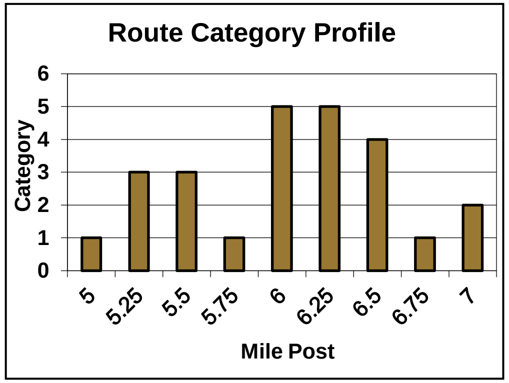
The Arboriculture and Forestry Advisory Group are the regulatory body for all tree felling operations in the UK. They publish guidelines on mechanical harvesting which must be adhered to as a matter of Health & Safety law (guides 603 and 704).

Other methods of vegetation management include erecting leaf fences (appendix A2.2.2) and removing dead leaves (appendix A2.2.3).

4.4.2 Vegetation Surveys

Infrastructure based control measures cannot be effectively targeted until the vulnerable routes and locations have been identified. This is best done as a collaborative exercise between the Infrastructure Manager (particularly their maintenance teams) and train operators. Section 3.5 provides advice on sources of data to assist in identifying locations suffering or likely to suffer from low adhesion problems.

In addition to the inputs from various historical sources, it is also necessary to consider where new problems may arise as previous good performance doesn't mean things won't change relatively quickly. In general, this should be based on route vegetation surveys where the density of trees and tree types can be quickly assessed using techniques such as that developed by British Rail – the 'Vegetation Severity Index' detailed in BR Research report LR/DS/92/030 "Autumn Leaf Fall: A Guide to Identifying Problem Locations".



Once a route has been 'profiled', the problem areas can be ranked. This will generally start by comparing the higher category areas in the route profile (Category 4 and 5) with the previous information gained from historical data and local knowledge. Priority areas are where the two coincide.

The remaining Category 4 and 5 sites should then be further assessed by determining whether trains are required to brake in these sections (for signals, stations, speed restrictions, etc.) or accelerate (particularly from stations and on steep gradients) or whether track circuit operation is likely to be a problem. In these cases, immediate attention is almost certainly going to be necessary.

Consideration should then be given to Categories 2 and 3 as to what steps may be necessary to ensure they do not become future Category 4 or 5 sites. Again, there should initially be an assessment of whether braking or acceleration is likely, whether there is potential for track circuit operating problems, and the tree types present.

4.5 Treating low adhesion

The fundamental requirement is to prevent contamination in the first place, but this cannot always be achieved and various treatments are available to remove or modify the contamination. Once the vulnerable sites, and contaminants, have been identified, the appropriate treatment can then be applied to retain or restore rail adhesion to levels high enough to support train braking and acceleration. These treatments can be applied proactively or reactively, i.e. cleaning rails once contamination has appeared.

Method	Application					Proactive	Reactive	Appendix
	RHTT	RRV A2.2.6	Fixed A2.2.7	Service Trains	Hand			
Water jetting	✓					✓	✓	A2.2.4
Sand solution	✓	✓		✓	A2.2.8	✓	hand	A2.2.5
Chemicals		✓	✓		✓	✓	✓	A2.2.10
Rail scrubbing		✓			✓		✓	A2.2.9

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4.5.1 Water Jetting and Sand Solution Treatments

It is now established practice in GB to undertake high pressure water jetting followed by laying a friction improver known as Sandite as the main remedial measure. Sandite is a sand solution of which examples include TG60 and Electrogel. Tests conducted by ARUP for Network Rail in autumn 2006 – 'Autumn 2006 Measurement Trials' – showed that there is strong statistical evidence to show that water jetting and a friction modifier results in higher train braking rates than water jetting alone (appendix A9.5). Water jetting and a friction modifier also resulted in more consistent train braking than water jetting alone. More recent analysis and testing has shown that TG60 can be deployed at faster speeds than Electrogel. Additional processes can be applied on a more localised basis, such as using static friction modifier laying equipment 'Traction Gel Applicators' (TGA), rail scrubbing equipment or hand applied sand or friction modifier dispensers.

The objective of water jetting is to completely remove the crushed leaf film or other contaminants from the railhead. Thus, the rail can be brought back into a clean state prior to the application of friction modifiers. More detail is in appendix A2.2.4.

The objective of adding a sand-based friction modifier (Sandite) is to help break-up leaf film on the railhead and to raise the adhesion level by the very action of introducing a friction improver (sand) into the wheel / rail interface. The physical presence of the treatment also provides a barrier to further contamination building up. In some cases, a metal particulate is added to aid the operation of track circuits to reduce risk from sand insulating the track circuit shunting. More detail is in appendix A2.2.5.

Managing Low Adhesion

With its fleet of Multi-Purpose Vehicles (MPVs) and Rail Head Treatment Trains (RHTT), Network Rail has implemented a programme of combined water jetting and Sandite laying, and in some cases water jetting alone. To be effective at 60mph, high pressure water jetting (1500bar) is first used on the leading vehicle to clean the rail and then Sandite is laid behind from the rear vehicle on the cleaned rail. A distinct advantage with this system is the ability to clean the rails and lay friction modifier at up to 60 mph. This reduces the impact on line capacity and allows more flexible operation.

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To put some metrics to this, over the approximate eleven-week autumn period, Network Rail's railhead treatment programme covers 650,000 miles to treat over 200,000 sites, delivering in excess of 130,000,000 litres of water and 1,300,000 litres of friction modifier.

It is inevitable that conflicts will exist between the competing demands for track occupancy from service trains, engineering possessions and the RHTT. Also competing demands will exist for traincrew when shortages occur. However, **priority should be given to the running of the treatment train as failure to do so may lead to significant delays and safety of the line implications for following service trains; it must not be cancelled unless absolutely essential**. The effects of engineering work on the treatment programme must be assessed in advance where pre-planned work is to be undertaken.

If cancellation of the railhead treatment programme in whole or part cannot be prevented, or if there are failures in water jetting / treatment laying for any reason, this should be immediately reported to the relevant Route Control Centre in order that train operators and their drivers can be warned. Network Rail's Supply Chain Operations (SCO) has implemented a 24/7 control function to monitor and support the delivery of the treatment programme.

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4.5.2 Potential future methods

In 2016, RSSB conducted a further knowledge search (S253) to identify how other industries respond to challenges around degradation of plant matter. Applicable techniques were found from a range of industries, including the biofuel and bioenergy, wood pulp and paper, textiles, food and beverage sectors, agriculture, waste management, animal feed, laundry and detergents and bioremediation. Industry solutions typically adopted a two-step approach:

- the degradation of lignocellulosic material (cellulose, lignose and hemicellulose);
- chemical or enzymatic pre-treatment to improve the efficiency of the digestion of lignocellulosic material by removing the surrounding polysaccharides.

Key findings of the knowledge search include:

- numerous industries are developing and using specific enzymatic and chemical solutions for biomass degradation;
- enzymatic solutions are used in process industries to control reaction conditions;
- an enzymatic solution should include an application method and optimisation of the enzyme;
- as ionic liquid solutions are currently emerging, they may not be cost effective. Cost-effective chemical solutions include hydrogen peroxide, and organic solvents such as methanol and weak alkalis.

For information on the chemicals and organic solutions already being deployed by Network Rail see appendix A2.2.10.

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4.6 Mitigating low adhesion by improving operations

Once the rails have been treated to mitigate the effect of low adhesion, there are still other precautionary measures that can be taken – by modifying operations.

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4.6.1 The sighting of signals

Another safety risk posed by vegetation is the obscuration of signals such that sighting becomes a problem for drivers. To provide sufficient sighting, foliage should be cut back far enough and for a long enough distance on the approach to the signal to provide at least seven seconds of uninterrupted signal sighting. This is not just a problem for the autumn. It applies all year round and will become a particular problem in the summer (the adjacent photo includes a 'hidden' signal just behind the 45mph Advanced Warning Indicator).

Whilst vegetation surveys play an important part in gathering intelligence; train operators should also check for the obscuration of signals by foliage as part of due diligence. Operators should programme cab rides in conjunction with representatives from the infrastructure manager. Drivers should also be encouraged to report areas where the sighting of signals is a problem. Footage from Forward Facing CCTV (where fitted) can also be invaluable (section 5.4.2).

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4.6.2 Platform stopping points

Consideration should be given to where trains normally stop in relation to signals and buffer stops. The position of stop boards at stations where stopping due to low adhesion may be a problem should be considered for re-siting, if these boards are too close to the signal and space permits. The addition of stop markers on the approach to buffer stops should also be considered to allow a safe ‘overrun zone’ should unexpected exceptional low adhesion conditions be encountered.

The provision of a ‘safe overrun zone’ however may not always be possible. Operators may consider a train stopping strategy for the service type operated on the route, e.g. an operator with a metro type service may consider the drivability of the route and have a near common stopping point for the platforms on any train journey.

4.6.3 Temporary speed restrictions

Temporary Speed Restrictions (TSRs) can have a significant effect on train operation during the autumn period. This will manifest itself mainly in additional train performance delays as trains struggle to re-accelerate after a TSR where adhesion conditions are poor. However, there is also a risk of trains over speeding the TSR as braking difficulties may be encountered on the approach to the TSR. Prior to the autumn, efforts should be made to ease or remove, where possible, those TSRs in locations likely to give rise to traction or braking problems.

4.7 Future initiatives

The following section explores some new initiatives currently being explored in the area of infrastructure measures.

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4.7.1 Biochemistry of Leaves

RSSB is funding the final year of a University of Sheffield PhD (COF-BIO-01) on low adhesion mechanisms and leaf layer bonding. The main aim of the project is to provide a detailed understanding of leaf film formation and bonding to rail, rail surface modification (i.e. a lasting effect post removal) and the tribological effects of a leaf film (including the effects of external parameters such as environmental conditions) before finally exploring novel mitigation methods. This work is due for completion in June 2018.

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4.7.2 Using tribo-chemistry analysis

Being delivered by the University of Sheffield (COF-E14-01), this PhD project aims to provide an understanding of the mechanisms leading to adhesion loss due to the ‘wet-rail’ phenomenon. Ink jet printing will be used to recreate the conditions in a laboratory environment, and tribological tests will then be conducted using a range of existing and emerging techniques to assess role of water and oxides and derive a suitable methodology for testing mitigation methods. The project is due to be completed in May 2018.

4.7.3 High resolution leaf fall monitoring

Being delivered by the University of Birmingham in collaboration with RSSB (COF-E14-02), this research sets out to produce a scientifically robust method to monitor leaf canopies at a high spatial and temporal resolution, from trains. It seeks to use differences in the spectral reflectance of trees as they move from full canopy to bare trees, enabling quantification of the amount of leaves falling on a daily basis. The project is due to be completed in June 2018.

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4.7.4 The tribology enigma

The Engineering and Physical Sciences Research Council (EPSRC) is funding a programme grant (COF-TRI-01) that will be undertaken by the University of Sheffield and University of Leeds to address tribological challenges faced by the rail, automotive and industrial lubricant industries. It aims to improve the understanding of friction mechanisms to improve train traction and braking performance, safety and increased network capacity. The programme commenced in September 2017 and is expected to continue until September 2022.

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5 Rolling stock measures

This section of the manual identifies the main technical issues involving rolling stock which can be addressed to manage train performance and safety as a result of low adhesion.

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5.1 Braking systems

The key safety risk arising from low adhesion is being unable to stop trains in a controlled manner. This increases the risk of overruns and collisions. This section is devoted to train braking systems.

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5.1.1 Tread and disc brakes

On most modern railway systems throughout the world there has been a general move to install disc brakes on passenger rolling stock. This has been mainly due to the desire of operators to provide a competitive, high speed, high frequency, quality service for its customers, whilst also allowing a reduction in operating costs. Disc brakes can meet all of these objectives unlike tread brakes which only meet some of them.

However, there is a belief amongst some drivers that disc brakes don't work as well as tread brakes when low adhesion conditions are present. A number of commonly held views about disc brakes were addressed by research and testing:

Belief	Conclusions from research and testing
Early disc braked trains were relatively lightweight and suffer more adhesion problems than the heavier vehicles they replaced, although more recent trains are heavier.	There are many more disc braked passenger vehicles operating than tread braked vehicles, therefore disc braked vehicles are more likely to encounter poor rail conditions purely on numbers.
Under extreme operating conditions, both tread and disc brakes can suffer from 'brake fade', i.e. reduced braking performance when the braking surfaces get too hot.	In practice, tread brakes are more prone to the problem than disc brakes as discs are designed to self-ventilate and can hence cool quicker than a wheel.
The WSP does not control the train as well as a driver can.	A good WSP assists the driver by matching the brake level demand to the prevailing rail conditions (which rise and fall along the track) independently on each axle.

Other conclusions were:

- tread brakes tend to 'bite' at low speed whereas disc brakes have a constant brake characteristic throughout the speed range;

- disc braked vehicles generally operate at higher speeds and with higher braking rates than tread braked vehicles, consequentially requiring higher adhesion levels for braking;
- new disc braked trains are often shorter than the trains they replace (due to their higher capacity per vehicle) thus offering fewer axles to assist in braking under poor rail conditions;
- lineside trees have increased in population since the introduction of disc brakes in the 1970's, leading to greater risk of low adhesion problems in modern times. Where possible, Network Rail are though actively removing trees in areas prone to low adhesion conditions.

A thorough review of the relative performance of the two brake types was conducted by BR Research and reported in BR Research report RR-SAM-135 “A Comparison of Tread & Disc Braking for Passenger Rolling Stock – With Particular Reference to Low Adhesion”.

This review concluded that the beliefs amongst traincrew arise mainly from the lower operating speeds and lower braking rates of tread braked stock, together with their rising brake friction characteristic as speed falls. These factors reduce the risk of wheel slide on tread braked trains at higher operating speeds, and give the impression of a more controllable brake at lower speeds. However, the review also concluded that:

- when rail conditions are good, i.e. able to support full braking demand, disc brakes are superior to tread brakes;
- when rail conditions are poor, for example when encountering drizzle, a good WSP will stop the train in a comparable distance to a tread braked train;
- when rail conditions are exceptionally poor, for example on untreated leaf contamination, neither a disc-braked or a tread-braked unit will brake in the normal distances, but a good WSP system will stop the train in the minimum distance the rail conditions will permit without damaging the wheels (if it is left to operate).

In 2014, RSSB found from a review of performance data (T1042) that, when leaf contamination is not present, tread brakes appear to be less susceptible to moist railhead conditions, e.g. morning dew. This may be because: tread brakes clear the wheels of contamination; or, contamination was formed on the wheel rather than the rail itself; or, where tread braked vehicles operate there might be more favourable local conditions that mitigate low adhesion situations developing.

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5.1.2 Dynamic brakes and blending

Modern rolling stock with electric traction uses the traction system to provide dynamic braking. This means that the normal friction brake is lightly used, allowing significant cost benefits to be achieved by reducing maintenance of the friction interfaces. However, the friction brake is still required:

- as an emergency brake for use in the event of a failure occurring within the traction braking system. In this case the friction brake is usually designed to support the full emergency braking performance of the train and the system will probably be configured such that the friction brake alone undertakes all emergency braking. However, not all trains are able to provide a fully rated friction only emergency brake and hence use the dynamic brake as well in emergency; a lower emergency braking rate being accepted for multiple failures of the dynamic brake system.
- as a 'top-up' brake at different parts of the speed range. The braking effort available from the dynamic brake may not be sufficient to provide the maximum required braking effort throughout the full operational speed range. In this case blending of the two braking systems is likely to be employed such that usage of the dynamic brake is maximised, with supplementary brake force blended-in from the friction brake as required.

The above generally works very well in normal, high adhesion operating conditions but the risk of wheel slide is increased when low adhesion is experienced. For example, if half the wheelsets are motored then the full braking effort will be shared across these when the train is operating in a speed range where blending is not employed. This will result in a doubling of the effective brake demand on half of the wheelsets. During the autumn, when defensive driving principles are used to reduce the risk of wheel slide, then a 'defensive' brake demand of 6%g (equivalent to brake step two on a three-step brake) would result in half the wheelsets seeing a 12%g brake demand, resulting in a 40-fold increase in the risk of the wheel slide! It could be concluded that this negates some of the benefits of defensive driving! In fact, this situation may not be as alarming as it sounds as long as the total braking system can respond well to the wheel slide situation and make the best use of the available adhesion, especially with optimised WSP and trainborne sanders.

So how does the braking system respond to the above situation? It may be tempting to use the aforementioned brake 'blending' function to apply the friction brake on all wheelsets so that the dynamic brake force may be reduced to a lower level. However, this can result in the two braking systems independently applying braking forces to a single axle at the same time. This would not present problems in high adhesion conditions, but is almost guaranteed to lead to reduced braking performance and wheel damage in low adhesion. If the wheels on the leading vehicle lock, that may also inhibit the activation of automatic sanding.

Under low rail adhesion conditions when all wheelsets are being controlled by the WSP to rotate at less than the true train speed (slipping), then neither the traction system nor the friction brake will know the true train speed with absolute certainty. The WSP will then rely on 'best guesses' based on the initial train speed before the slip occurred and the rate of change of wheelset speed. In addition, the WSP for the friction brake will almost certainly try to release the brake briefly on one wheelset to allow it to return to the true train speed. This, in turn, resets the internal 'best guess' of the train speed to a much more accurate figure.

So, what happens when both systems are independently applying braking forces to the same wheelset? It is very likely that it will not behave in the manner that the WSP control system expects. For example, the friction brake may reduce the brake force to allow the wheel to return to true train speed, whilst the dynamic brake may apply more brake force because the wheel is accelerating. The net result is that neither system will be capable of making an accurate estimate of the true train speed and wheel speeds may drift until they eventually stop rotating. This process is not making best use of the available adhesion, can result in wheel damage and may prevent automatic sanding.

Modern blending systems work in a variety of ways, for example:

- A system can be provided that has different blending philosophies depending upon the conditions. Traditional blending systems initially apply the dynamic brake to the maximum level on the motor bogies, then make up the additional brake effort required on the trailer bogies. If any further friction brake effort is required, this is then added to the motor bogies. The drawback with this method is that the pad / block wear on the trailer axles (and the wheel wear on tread braked wheels) is higher than the motor bogies. Also, it means that the trailer axles have a lot more thermal input. The aim on modern trains is often to balance out the friction brake effort in order to balance wear and reduce thermal loading on some bogies. Hence, the system applies the dynamic brake up to its maximum capacity, then applies the friction brake equally as far as possible on all bogies. Only when the adhesion limit is reached on the motor bogies is the level increased on the trailer bogies.

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- Although this system equalises wear as far as possible, it means the train is more likely to slide, as the adhesion demand on the motored axles is always high. Hence, some systems can then be switched to an 'autumn mode', where the system works more like the traditional method, but also balances the adhesion demand across all axles, both in the dynamic brake force demand and the friction brake effort added to the axles.
- Knorr-Bremse are also able to offer a system whereby the brake unit will control the dynamic brake during WSP. It gives signals to the local traction control unit for each car / bogie / axle to reduce or hold the dynamic brake effort in parallel with the signals it uses to control the pneumatic valves to change the brake cylinder pressure during wheel slide. Such a system eliminates the conflict that can occur between a traction and a friction brake WSP system.
- Knorr-Bremse have also produced blending systems that monitor the dynamic brake effort during wheel slide and if the reduction in this force exceeds set criteria (as the traction system attempts to control the slide), it will redistribute this effort onto the other trailer axles in the braking network and reduce the dynamic brake demand to a lower level.

Despite this, the 'significant cost benefits achieved by reducing maintenance of the friction interfaces' are still to be realised throughout the year when 'normal' adhesion conditions prevail. Low adhesion conditions persist for less than 1% of the year so that the use of the friction brake is still quite limited. Equally importantly, the low level of wheel / rail adhesion restricts the maximum brake force that can be achieved, so the corresponding brake wear will be lower. Any increased friction brake maintenance costs are likely to be more than offset by the reduction in wheel damage.

Two final points on blending:

- Due to the efficiency of modern dynamic brake systems, there is an increasing risk of the brake blocks or pads seeing little use in normal service and becoming polished or glazed. This effect can significantly reduce the friction level of the blocks / pads when they are called upon for a friction only application, particularly in wet conditions. In view of this, the brake blending system or train control should incorporate features to prevent this occurrence, such as regular friction only braking stops on one or more bogies. This should be considered with the design of the brake control system at the same time as the development of the control system to optimise the blending process in low adhesion conditions.

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- In 2012, RSSB investigated the benefits of adopting an all-electric brake philosophy on Britain's mainline railway (T860). This research examined current developments in electric traction braking as a means of reducing the requirement for, or even eliminating, the need for a pneumatic (friction) brake system. The research found evidence of greater use of dynamic braking outside the GB railway for service and emergency braking, and provided evidence of potential efficiencies and savings that electric brake systems can provide and how they can be introduced to GB railways. Accordingly, this research suggested that all-electric braking is plausible with the technology already in place.

A vision of an all-electric brake train

An all-electrically braked train would probably have a higher percentage of motored axles than current and will likely be fitted with a mix of eddy current track brakes and electrical friction brake actuators. The dynamic brake would need to be active in emergency brake and wheel-slide protection available at all times. The electric friction brake actuators would be part rated and retain a limited 'failsafe' emergency brake function. Permanent magnet motors are likely to be a significant feature of future traction systems and these offer the possibility of safety critical braking.

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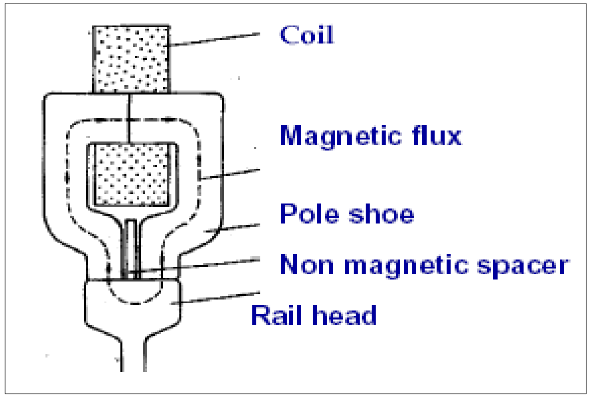
5.1.3 Magnetic track brakes

Magnetic track brakes (MTB) are a form of brake that is mounted on the vehicle bogie frame between the wheels. When this brake is lowered to contact the rail a magnetic clamping force generates friction between the MTB and the rail; the friction force decelerates the train. This clamping force arises from a magnetic circuit between the MTB pole pieces and the steel rail, clamping the pole shoes to the rail and hence creating a braking action (friction) as the pole pieces slide along the rail. While MTBs are believed to have a beneficial cleaning effect on railhead contamination by removing leaf film, their braking performance can nonetheless still be affected by low adhesion although less so than braked wheelsets. In their report into the collision of two trams at Shalesmoor in October 2015, RAIB concluded that the performance of friction-type MTB can be adversely affected by railhead contamination in a similar way to the friction brakes on the wheels.

More information is provided in appendix A2.3.1.



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5.2 Optimising braking performance

Having discussed braking systems in the previous section, this section focuses on optimising their performance.

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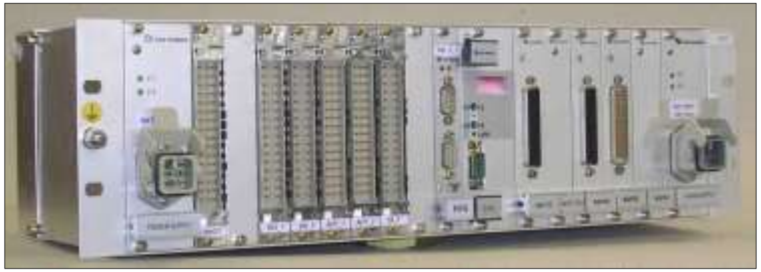
5.2.1 Wheel Slide Protection systems



Wheel Slide Protection systems (WSP) are fitted to all disc-braked passenger rolling stock (and some freight vehicles) because of the higher retardation rates being more likely to induce wheel slip. The objective of a WSP system is to minimise the inevitable extension in stopping distance when low adhesion conditions occur, whilst reducing the risk of significant wheel damage. WSP operates by modulating the brake actuators of slipping wheelsets, releasing and re-applying the brake at appropriate levels to maximise use of available adhesion. By controlling the speed of the wheelset to just below the forward speed of the train ('slip speed') a conditioning effect is seen which actually improves adhesion levels along the train as successive wheelsets condition the railhead.

In 2008, RSSB sponsored research by DeltaRail Group into understanding how train control systems influence adhesion performance (T545). The results suggested that high levels of rail conditioning could benefit braking performance. This could be achieved by increasing the level of slip above the 15 to 20% level at which modern Wheel Slip Protection (WSP) systems operate. However, tests have also shown that increasing the slip levels above 20% could increase the risk of martensite formation in both wheel and rail leading to cavities, although this is dependent on the source of low adhesion. This target level of slip of 15 to 20% is the range used by some suppliers to achieve the optimum performance on WSPER (appendix A2.3.2) and covers a range of adhesion conditions. Different levels of slip may produce better results under certain specific conditions; some modern WSP systems include adaptive algorithms that adjust the control behaviour between low and extremely low adhesion conditions.

More information is provided in appendix A2.3.2.

5.2.2 Trainborne sanders

Britain's railway has many years' service experience with multiple unit sanders, with all multiple units with disc brakes now fitted, and all post 1970s tread braked multiple units also fitted. Current designs for disc braked units are of the Automatic Sanding Device (ASD) type, controlled by the WSP system and available in both braking and traction, the latter being manually controlled. This includes 'variable rate sanders' where the sanding rate is increased depending on train speed and brake demand. Sanders fitted to tread braked units are manually controlled in both braking and traction because there are no WSP systems to automate the process. Retrofitting WSP to such units (appendix A2.3.2) would therefore allow automatic control of the sanding system as an added bonus.

More information is provided in appendix A2.3.3.

5.2.3 Auxiliary tread brakes

Auxiliary Tread Brakes (ATB) have been fitted to a limited number of disc braked vehicles and are thought to aid track circuit operation by cleaning and roughening the wheel treads. Their ability to improve low adhesion is considered small as they act only to clean and roughen the wheel treads and not the railhead where most of the contamination is to be found. ATBs are explained further in appendix A2.3.4.

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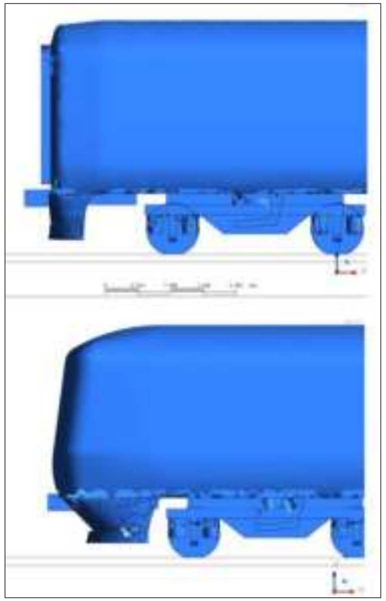
5.2.4 Aerodynamics to reduce contamination

The main cause of leaves being in the wheel / rail nip to be crushed by the wheels is the slipstream created by the train itself as it moves along. As seen in section 4.3.1, the air turbulence draws up leaves from the four foot and the trackside and, depending on the train's aerodynamic effects, sucks them into the path of the wheels. One way in which the amount of leaves being crushed on the rails can be minimised is to design the vehicle such that the aerodynamic effects tend not to draw leaves into the path of the wheel.

Attempts have been made in the past to influence this effect both by trainborne and trackside solutions. This was prompted by an increase in low adhesion problems found with new rolling stock when introduced in the 1980s. Practical tests had confirmed that the new trains deposited more leaves than those they replaced, by as much as two-fold. The tests identified that the length of the train formation affected the number of leaves deposited on the railhead, but the number was not proportional to the train length. Train speed was also a major factor affecting the number of leaves trapped by passing trains.

Later, following a rise in wrong side track circuit failures in the early 1990s, full-scale tests were carried out by BR Research with Class 156, 158 and 165 two-car DMUs, with different front-end configurations. Tests were made by passing over sheets of paper laid on the track bed to represent leaves. Three colours of paper were placed in the four foot, six foot and the cess so that after the train had passed the numbers of leaves left, moved to and from each region and squashed on the railhead could be counted. The tests showed that the number of leaves left squashed on the railhead after a two-car sprinter type DMU had passed over was highly dependent on both the presence and type of air dam fitted to the front of the train.



A snowplough fitted Class 156 squashed 3.5 times as many leaves compared to the same unit without any such device. The Class 158 (fitted with a standard fibreglass air dam) squashed slightly fewer leaves on the railhead than the snowplough fitted Class 156, but still a factor of three times greater than the Class 156 without snowploughs. The integral snowplough type air dam fitted to the Class 158 resulted in an even greater number of leaves deposited on the railhead. This was worse by factor of 1.7 on the number deposited by the standard air dam fitted Class 158 and hence a factor of 4 times worse than the Class 156 without snowploughs.

The Class 165 fitted with its standard air dam, which is significantly different to that of the Class 158 unit, only squashed a similar number of leaves to the railhead as the Class 156 without snowploughs.

Videos were taken of the simulated leaf movement tests carried out on the Old Dalby test track during 1992. Analysis of these revealed that the leaf movement varied considerably between different unit types and configurations. The variation was much larger than expected. In particular, the leaf movement was identified that caused the Class 158 with obstacle deflector, all the integral snowploughs, and the Class 156 with snowplough fitted, to squash many more leaves on the railhead compared to other units or configurations. Leaves in the cess are initially pushed out as the front of the train and first bogie passes and were drawn back to the railhead as the open region of the latter half of the first vehicle passes. Two strong small vortices in nip of the railhead caused the leaves in the four foot and in the cess to be captured and held in this region resulting in a number of them being run over by the vehicle wheels. The Class 156 in the open configuration and Class 165 with its standard air dam fitted, both produce completely different leaf movement from each other and from the Class 158 or 156 with snowplough, such that for the Class 165 and Class 156 in the open configuration, few leaves are transferred across the railhead. A very limited understanding of the leaf movement caused by the front air dam was developed:

- the more bluff the air dam / obstacle deflector the stronger are the vortices created by it and hence the trapping of more leaves;
- the actual size, position, strength and direction of rotation of the vortices created underneath and to the side of the train are a consequence of the geometry of the air dam.

Tests demonstrated that vehicle-borne leaf deflectors were effective in reducing the amount of leaf coverage on the railhead. The improvement obtained for real, large sycamore leaves was about 70% to 80% using a deflector mounted around the wheelset. However, such devices are inhibited by several issues including mechanical robustness and maintainability.

Further research was undertaken by RSSB in early 2000s to gain a better understanding of the airflow properties and develop guidance for designers based on computer modelling and wind tunnel testing (T546).

Wind tunnel work at Southampton University and associated Computational Fluid Dynamics (CFD) computer models have increased our knowledge of airflows around and under vehicles, and validated CFD as a usable tool for assessing critical airflows that may influence leaf movement. Unfortunately, from this theoretical work, it has not been possible to identify with any certainty which features of a train design are responsible for a vehicles propensity to squash leaves on the line. However, it has been possible to identify some flow / turbulence / wind speed factors which show major differences between a vehicle with good characteristics (e.g. Class 165) and one with poor characteristics (e.g. Class 158). For example, a positive pressure field ahead of the train (pushing leaves down) followed by a negative pressure field ahead of the leading bogie (creating upwards air flow) is more pronounced on a Class 158 than on a Class 165. Also, the bluff front end of the Class 158 creates much more erratic flow around the vehicle sides compared to the smooth airflow off the rounded front end of the Class 165. Further tests on a Class 158 were recommended but did not proceed.

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5.3 Improving train detection – Track Circuit Actuators / Assisters

The objective of the Track Circuit Actuator / Assister (TCA) is to assist the operation of track circuits by breaking down the electrical insulation properties of certain contaminants on the railhead. TCAs are explained further in appendix A2.3.5.

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5.4 Improving information

As well as efficiently stopping trains through effective braking and reducing the effects of contamination, trainborne systems can also provide a wealth of information that helps to manage and mitigate the effects of low adhesion. This section explains them.

5.4.1 On-Train Data Recorders

Although On-Train Data Recorders (OTDR) have no direct effect on preventing low adhesion incidents, they can provide valuable information to help train operators identify the causes of incidents. This in turn can prevent further such incidents if the data recorder output is used constructively, for example in helping train drivers improve their driving techniques or for monitoring driver competence. Coupled with GPS, OTDR data can also provide accurate positional information.

More information is in appendix A2.4.3.

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5.4.2 Forward Facing CCTV

Most mainline trains are now fitted with a CCTV camera looking ahead of the train (adjacent). Depending on resolution, such devices could provide information on track condition, trackside vegetation, etc. Such cameras can be particularly valuable to train operators for checking the sighting of signals to identify foliage issues, sharing extracted photos with Network Rail to support driver's reports. Footage may also be used to benchmark the foliage on the route and use as a comparison for future reviews. The cameras have also been used during buffer stop collision investigations to verify the speed of impact.

Greater Anglia has also used GoPros fitted to one of their vehicles, to enable quick identification of vegetation issues as part of autumn preparation (still of video adjacent).

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5.5 Procuring new trains

The autumn of 2005 exposed a number of issues associated with how new trains were managing low adhesion. This resulted in an industry investigation (the 'Goff' report) and a Rail Accident Investigation Board (RAIB) investigation. Some key messages have emerged for those involved in procuring new trains to ensure the best possible start in life with regards to adhesion management:

- read the RAIB reports into the 2005 adhesion incidents and ensure that prospective suppliers have also studied the reports;
- read the AWG report on the same period, the 'Goff Report', and this manual 'Managing Low Adhesion', and ensure that prospective suppliers have also studied the report and manual;
- quiz suppliers in depth at tender evaluation stage on their designs for WSP and sanding and talk direct to the suppliers of the sanding and WSP sub-systems;
- ensure suppliers have covered all the issues in respect of systems integration – that there is no possibility of perverse interaction between the normal braking control, WSP and sanding systems (particularly where regenerative braking is used);
- be prepared to challenge, or obtain advice on, interpretation of standards particularly with regard to sanding rates and sander positions;
- make sure the balance of risk in sanding, between needing to stop the train in an emergency and the risk of interference with infrastructure, has been argued through to achieve an optimised system;
- integrate monitoring of WSP and sanding activity with the overall onboard data management and remote condition monitoring (RCM) capability of the train.

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5.6 Future initiatives

The following section explores some new initiatives currently being explored in the area of rolling stock systems.

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5.6.1 Low adhesion braking model (LABRADOR)

Being delivered by the University of Huddersfield (COF-UOH-12) in collaboration with RSSB, this PhD project aims to develop a computer simulation tool for assessing braking performance and behaviours of the whole train during low adhesion conditions, and in normal wheel-rail conditions. It will bring together the many factors that interact to enable a train to brake effectively (or not) in low adhesion conditions: wheelsets, wheel-rail contact patch adhesion, dynamic brakes, friction brakes, sanders and vehicle and train brake controllers. These components are relatively well understood in isolation, but when coupled together in a train they become complex. The project is due to be completed in 2018.

5.6.2 Sand particle entrainment and its effects on the interface

Being delivered by the University of Sheffield (COF-ITR-02) in collaboration between RSSB, this PhD project aims to provide a detailed understanding of how particles are entrained into the wheel / rail interface. It will explore the effect particles have on the friction in the interface (particularly in low adhesion conditions), leaf layer removal, wheel / rail isolation (which potentially affect track-circuits), and the wheel and rail material damage. The research will focus on experimental characterisation of different particles and develop appropriate models of particle behaviour. The project is due for completion in October 2020.

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6 Train detection measures

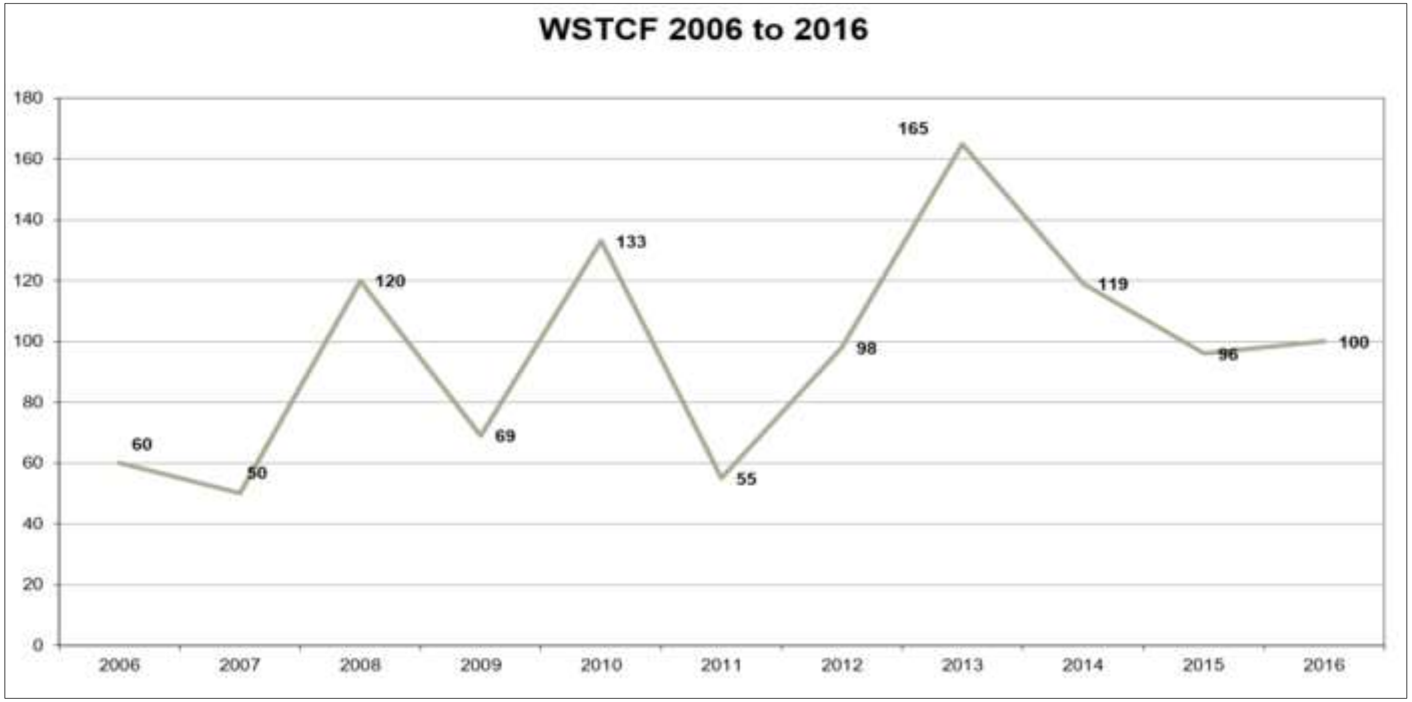
An unwanted side effect of some forms of rail contamination, and indeed possible from some forms of low adhesion remedial treatments such as those involving sand, is a failure of the train to activate a track circuit. These incidents occur when the conductivity of the wheel / rail interface is insufficient for the track circuit to detect the presence of a train. Such failures, known as Wrong Side Track Circuit Failures (WSTCF), have the **potential** for safety related incidents with severe consequences such as train collisions, or failure of other signalling related equipment to operate level crossing barriers for example.

Much research into this phenomenon was undertaken by BR in the late 1980s / early 1990s following the introduction of new diesel multiple units which were causing more WSTCFs than the units they replaced. It was noted that low voltage DC track circuits were particularly vulnerable to problems where modern diesel multiple units with good riding bogies and disc brakes operated. A range of solutions were found for the most common cause of WSTCF; rust film on the rail. However, such solutions are not always effective for other causes of WSTCF such as dry leaf film and excessive applications of friction improvers such as TG60, Traction Gel or sand. As a result, the railway suffers a number of WSTCFs every year.

The first priority is to identify vulnerable locations so that mitigation measures may be implemented. Such locations do not necessarily coincide with low adhesion locations identified for traction or braking problems, as track circuit failures can occur at locations where trains normally do not need to accelerate or brake. It is also rare to have both adhesion and track circuit problems at the same time since poor adhesion requires damp conditions, while poor track circuit performance requires dry conditions.

Several measures are available to control or mitigate the effects of WSTCF, ranging from technical solutions on the infrastructure or on trains prone to regular failures, through to procedural intervention for occasional failures. Attention should also be paid during vehicle design to assure track circuit operation. This section of the manual identifies the main issues involving loss of train detection during the autumn period and methods of controlling this. Reference should also be made to AEA Technology report AEAT-T&S-2000-101 "Review of Initiatives – Wrong Side Track Circuit Failures", August 2000, which provides further details of issues associated with WSTCFs.

The graph below shows the number of WSTCFs reported year by year. However, note that in recent years the advent of Remote Condition Monitoring (RCM) is believed to have led to more events being detected than when relying on signallers spotting loss of detection. Appendix A9 provides some further details of recent reviews of WSTCF performance.



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6.1 Operational procedures

Not all WSTCF incidents have the potential to lead to serious consequences if appropriate operational procedures are implemented. Once a WSTCF has occurred, the potential for incidents at that location and with that train can be minimised by instituting special working arrangements. Such arrangements are detailed in Rail Industry Standard RIS-3708-TOM “Arrangements Concerning the Non-Operation of Track Circuits During the Leaf Fall Contamination Period”. In line with this standard, special working arrangements are to be implemented for any location affected by wrong-side track circuit failures caused by leaf fall contamination. However, implementing such arrangements compromises train performance and line capacity.

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6.1.1 Signalling controls

Where practicable, signalling equipment should be operated to avoid the need for signals to be passed at danger. The affected section should be capable of being protected by a signal under the direct control of the signaller. The signaller should be able to establish that a train has passed clear of the affected section before allowing a subsequent train to proceed beyond the controlling signal.

Where points are normally locked by track circuits but the track circuits are not functioning correctly, the points should not be operated until the train is well clear. The individual point control devices should be used on a route setting system. Reminder appliances should be used as appropriate on the switches / levers for points and signals.

Extra vigilance by the signaller in the observation of the correct operation of track circuits is required where there is a higher than normal risk of trains not being detected. Examples of this are the passage of a Rail Head Treatment Train when laying and the train following it; a train with a failed Track Circuit Actuator; and the train following one which has deposited significant amounts of sand (e.g. after the firing of an Emergency Sanding Device).

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6.1.2 Level crossing controls

Where automatic level crossings are operated solely by track circuits in the affected area, drivers should be instructed to stop and not proceed over the crossing until it is safe to do so. Level crossings with auto-raise facilities should be operated on manual raise, and where barrow crossings or other warning apparatus are operated solely by track circuits, appropriate instructions should be issued to ensure the safety of users or the equipment disconnected.

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6.1.3 Other warning systems

Train Operated Warning Systems (TOWS) should be taken out of use.

6.1.4 Double blocking

By instituting rules which require two signalling sections to be proved clear between successive trains, the risk is reduced as the likelihood of a train failing to operate track circuits at consecutive signal sections is much lower. This obviously impacts track capacity.

6.1.5 Examination of the train

If it is suspected that a particular train is causing track circuit detection failures, then the train wheelsets should be examined, if necessary by the driver at the first opportunity, to identify whether it is required to take the train out of service. Drivers, of course, need to be trained in what to look for on the wheels.

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6.1.6 Service / fleet withdrawal or diversions

Diversions should be considered where it is practicable to route trains off the affected section of line / area. In extreme cases, withdrawal of, or limitations upon, the use of specific fleets or vehicles on specified routes should be considered. DMUs should not be permitted to run over the sections of line where Automatic Half Barrier level crossings are operated solely by track circuits.

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6.1.7 Hybrid / mixed train operations

Disc braked DMUs with modern, high quality bogies are more vulnerable to WSTCF through leaf debris building up on the wheel treads. The mixing of disc braked with tread braked units, or the addition of tread braked vehicles into disc braked units (hybrid formation), can assist in but not guarantee, ensuring that track circuits are correctly operated in vulnerable areas.

Also, if routing options allow, running locomotive hauled freight trains along routes normally only used by passenger multiple units will assist clearing contamination from the rails. This may be particularly effective where there is a history of track circuit operating problems in the autumn. One example of this has been on the Test Valley line where low voltage DC track circuits were historically affected by contamination. The route was operated predominantly by Class 158 DMU which do not ‘scuff’ the rail significantly. By diverting three Freightliner trains a day over the route, the number of track circuit operating problems reduced significantly.

6.2 Reducing contamination

Network Rail and train operators deploy various methods for reducing contamination on the rails and the wheels to improved adhesion and reduce the risk of WSTCFs.

Water jetting and sand based railhead treatments

Initiatives to combat the problem of braking or accelerating on low adhesion, for example water jetting and sand based railhead treatments, could also be effective in breaking up the leaf film at critical sites. They thus have the potential to reduce the risk of track circuit actuation failure in dry operating conditions if applied with sufficient frequency.

A number of remedial measures adopted to combat the safety and performance problems of low adhesion, particularly leaf film, currently use sand as a medium for improving adhesion (section 4.5.1); hand sanding in various forms (appendix A2.2.8) and trainborne sanders (section 5.2.2).

The application of sand to the wheel / rail interface when low adhesion conditions are experienced has major advantages in that the action of the sand ground in to the wheel / rail interface is likely to break up the film and improve track circuit actuation. That said, there has in the past been concern about excessive sand itself causing track circuit actuation problems as sand is a good electrical insulator. Work by RSSB in 2015 (T1046) suggested this is not the case. It concluded: reliable sanders and the use of enhanced sanding capabilities (un-suppressing sanders on trailing multiple units) could deliver a significant reduction in the frequency of low adhesion SPADS – the reduction in SPAD risk was at least 170 times greater than the current risk associated with WSTCF caused by sand contamination.

Note also, that sand from trainborne sanders will only be applied when the adhesion is low, i.e. when moisture is also present. Hence it should not be assumed that trainborne sanders will assist the track circuit actuation problem associated with dry leaf film and alternative measures must be employed. More information is in appendix A2.

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Auxiliary tread brakes

There is clear evidence that tread braked vehicles are less likely to be involved in WSTCFs than disc-braked vehicles. It is not totally clear whether the improvement is due to surface roughness of the wheel tread or the presence of brake block dust. Analysis undertaken in 1992/93 following the fitment of ATBs identified that the fitted fleet were 50% less likely to be involved in WSTCF incidents. More recent analysis during 2002 and 2003 revealed almost no incidences of WSTCF involving DMU fitted with ATB. However, while analysis has shown WSTCF benefits, experience has shown that tread conditioning has little value for increasing adhesion levels as it has no effect on the rails where most of the contamination is to be found. ATBs are explained further in appendix A2.3.4.

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6.3 Improving track circuit performance

Once the risk of WSTCFs has been mitigated through operational procedures and reducing the contamination in the first place, the performance of the track circuits themselves can be improved to reduce the impact of low adhesion. The ultimate solution is to replace track circuits with ERTMS Level 2 and 3.

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6.3.1 Track circuits

Sequential track circuits

Another technical solution that can be employed at vulnerable sites is the application of sequential track circuits. Put simply, sequential track circuits operate so as to always maintain the specific track circuit until the track circuit ahead is detected as shunted.

Limitations

- Restoration;
- Increased risk / impact of failure.

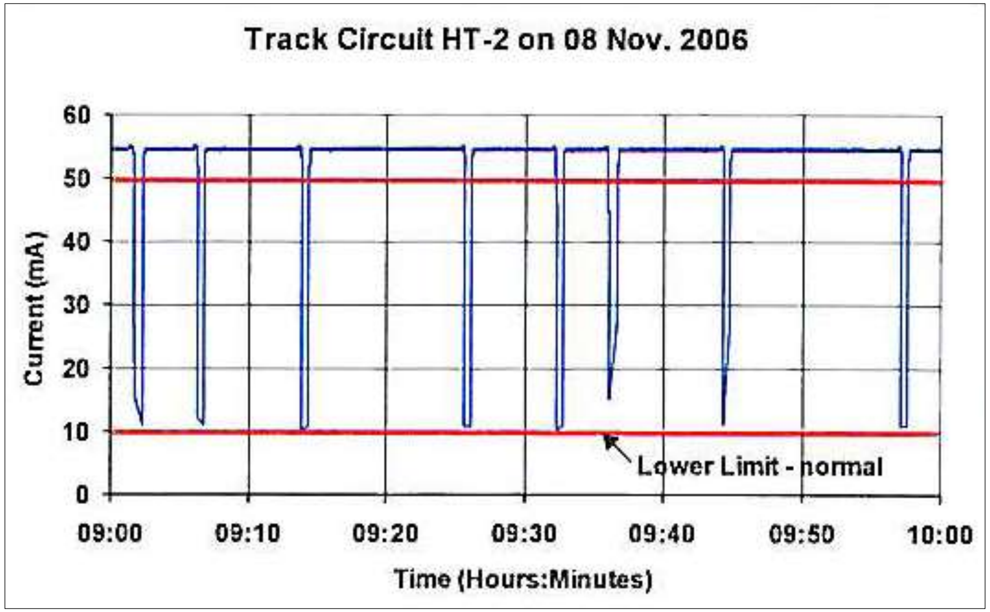
DC track circuits

Analysis of WSTCF data has in the past shown that the dominant factors are disc-braked DMU operating over areas with DC track circuits. Research by RSSB in 2015 (T1046) suggested that low voltage DC track circuits are more susceptible to WSTCF due to contamination, and the replacement of these circuits could reduce the rate of WSTCF due to contamination by up to 90%. Whilst, the replacement of DC track circuits is an option, it requires careful evaluation against the cost of other options.

6.3.2 Track circuit monitoring

Track circuit monitoring devices, such as the ACIC Ltd logging device, can be used to monitor the performance of track circuits and alert against pre-determined events such as reduced shunt current levels indicating the presence of an insulator (e.g. leaves).

The picture below shows a typical output from a track circuit monitoring device. Each drop in the current represents a train passing through the track circuit.



Threshold limits can be set to detect varying performance and enable track staff to react to emerging conditions and prevent a WSTCF occurring.

Network Rail's Intelligent Infrastructure Remote Condition Monitoring platform is now monitoring around 23,000 track circuits. This is showing benefits in reduced WSTCF incidents, consequently reducing train delays and the risk to safety.

6.3.3 Track Circuit Actuators / Assister

The majority of initiatives to address the problem of WSTCF have been targeted at rust on the railhead. This is a semi-conducting layer which can be successfully broken down, for example, by traction return voltage on electrified lines, and the voltage induced by a Track Circuit Actuator / Assister (TCA). More detail is provided in appendix A2.3.5.

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6.3.4 Track Circuit Actuator / Assister Interference Detectors

As detailed in section 6.3.3, TCAs have been fitted to modern DMUs to aid the operation of track circuits. Track Circuit Actuator / Assister Interference Detectors (TCAIDs) can be used to indicate the presence of a train by shunting the track circuit independently of contact between the wheels and rails. This technique relies on the fact that all TCAs transmit a common high frequency signal into the rails. This frequency can be detected (as a voltage) in the running rails for a few hundred yards at either end of the train by a simple track mounted receiver. The TCAID then operates the track circuit independently of any wheel / rail contact. More detail is provided in appendix A2.2.11.

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6.3.5 Design for Reliable Track Circuit Operation

Rail vehicles must be designed to reliably operate track circuits by presenting a minimum shunt performance across the rails. Railway Group Standard GK/RT0028 “Infrastructure Based Train Detection Interface Requirements” and Rail Industry Standard RIS-0728-CCS “Infrastructure Based Train Detection Systems”, provide the overall requirements for train detection systems.

6.3.6 Axle Detector

In critical areas subject to track circuit failures during the leaf fall season, consideration should be given to fitting automatic level crossings with wheel detection systems such as Silec treadles or electronic wheel detectors; the majority of automatic crossings will now have treadles or electronic wheel sensors installed. These systems are effective and can be used at speeds up to 100 mph.

Axle counters are now becoming more commonplace in Britain offering track circuit operation without relying on wheel / rail contact. As they replace conventional track circuits, then WSTCFs will become less common.

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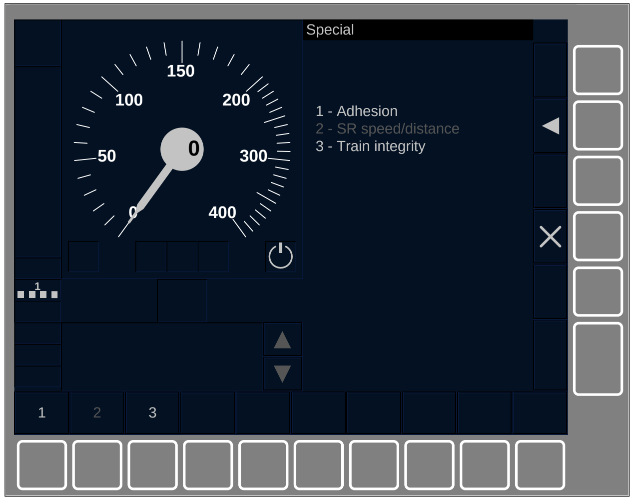
6.3.7 ERTMS

Transmission based signalling will be the main method of future signalling throughout Europe. Systems such as the European Train Control System (ETCS) at Levels 2 and 3 remove the need for conventional track circuits, and hence remove some of the risk to train detection from rail contamination. However, such systems will not alleviate the problems that low adhesion brings to acceleration and braking, and unless carefully managed, may increase the problems particularly where lineside signalling is to be removed (ETCS Level 2) and moving block signalling is introduced (ETCS Level 3).

ETCS is part of the European Rail Traffic Management System (ERTMS) intended for future roll out across core routes. The intended application of ETCS in Great Britain is 'Level 2' which, instead of lineside signals, uses the GSM-R radio network to transmit movement authorities to the driver via an in-cab display (Driver Machine Interface). In essence, this means that trains may need to accelerate and brake at different locations than they do today with lineside signals sectioning up the route. Traditional route knowledge of low adhesion sites may therefore no longer be enough.

It is also fundamental that ETCS remains fully operational throughout periods when a train is experiencing wheelspin or wheel slide, which of course is highly likely under low adhesion conditions. Wheelspin may cause the on-train equipment to think it has travelled further than it has and require braking earlier than really required affecting performance. More critically, wheel slide would cause ETCS to think that more distance was available for stopping than was actually the case, potentially impacting safety. Accurate and sophisticated odometry is therefore essential and a cornerstone of the ETCS specifications, using track mounted 'balises' to pinpoint train position.



The ETCS system design also permits an 'adhesion level' to be set which alters the assumed braking rate for the target stopping and Automatic Train Protection (ATP) functions. A command can be sent from the trackside system to the train, or the driver could select the low adhesion setting. The setting adjusts the braking curves to 70% of their normal values.

This ETCS function is a general area of concern as the selection of the low adhesion is presently a crude function. Line capacity and performance could be affected if the adhesion setting is left on when not necessary. Equally, if the setting is applied too optimistically, then rail conditions may be inadequate to provide the required levels of train protection. Like most European countries, it is currently not proposed to use this function in GB and drivers of ETCS-equipped trains are expected to control the speed of the train in accordance with the prevailing rail conditions, just as they do for conventional signalling systems.

7 Abbreviations

AAI	Autumn Adhesion Index
ACC	Adhesion Control Centre
ACCAT	Adhesion Controller's Condition Assessment Tool
AMS	Adhesion Management System
ARG	Adhesion Research Group
ASD	Automatic Sanding Device
ATB	Auxiliary Tread Brake
ATO	Automatic Train Operation
ATP	Automatic Train Protection
ATUST	Adhesion Treatment Using Service Trains
AWG	Adhesion Working Group
AWS	Automatic Warning System
BR	British Rail
BSI	British Standards Institute
CCS	Control, Command and Signalling
CCF	Control Centre of the Future
CEN	Comité Européen de Normalisation
CFD	Computational Fluid Dynamics
COSHH	Control of Substances Hazardous to Health (Regulations)
CPL	Carriage Packing and Labelling (Regulations)
DMI	Driver Machine Interface
DMU	Diesel Multiple Unit
ECD	Eddy Current Device
EMU	Electric Multiple Unit
ERA	European Union Agency for Railways
ERTMS	European Rail Traffic Management System
ESD	Emergency Sanding Device
ETAMS	European Train Adhesion Management System
ETCS	European Train Control System
EWAT	Extreme Weather Action Team
FAMS	Fleet Asset Management System
FWI	Fatality and Weighted Injuries
GB	Great Britain
GIS	Graphical Information System
GPS	Global Positioning by Satellite
GSM	Global System for Mobile communications
GSM-R	Global System for Mobile communications - Railways
HST	High Speed Train
IBJ	Insulated Block Joint
KPI	Key Performance Indicator
LAWS	Low Adhesion Warning System
MOM	Mobile Operations Manager

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MPV	Multi-Purpose Vehicle
MTB	Magnetic Track Brake
NOACR	Network Operations Autumn Cumulative Report
NOADR	Network Operations Autumn Daily Report
NSC	National Supply Chain
NTF	National Task Force
OTDR	On Train Data Recorder
PADS	Poor Adhesion Display System
PPM	Public Performance Measure
PR	Public Relations
RAIB	Rail Accident Investigation Branch
RCF	Rolling Contact Fatigue
RCM	Remote Condition Monitoring
RGS	Railway Group Standard
RHTT	Rail Head Treatment Train
RAIB	Rail Accident Investigation Branch
RSSB	Rail Safety & Standards Board
SCO	Network Rail Supply Chain Operations
SMD	Specially Monitored Driver
SMIS	Safety Management Information System
SMS	Short Messaging Service
SMT	Seasons Management Team
SRM	Safety Risk Model
SSSI	Site of Special Scientific Interest
TCA	Tract Circuit Actuator / Assister
TCAID	Tract Circuit Actuator / Assister Interference Detector
TGA	Traction Gel Applicator
TRUST	Train Running System TOPS
TSI	Technical Specification for Interoperability
TSR	Temporary Speed Restriction
UIC	Union Internationale des Chemins de Fer
V/T SIC	Vehicle / Track System Interface Committee
WSP	Wheel Slide Protection system
WSPER	WSP Evaluation Rig
WSTCF	Wrong Side Track Circuit Failure
WTT	Working Timetable

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8 Glossary

Adhesion (coefficient of)	The coefficient of rolling friction in wheel to rail rolling contact. It is the ratio between the maximum longitudinal force that can be applied tangentially to the wheel at the wheel/rail interface and the component of vehicle weight acting perpendicularly through the wheel radius to the rail.
Autumn Adhesion Index (AAI)	A predicted measure of risk likely to be encountered on an autumn day.
Automatic Sander Device (ASD)	A trainborne sander that is automatically controlled by the selection of a specified brake demand level together with WSP activity, depositing a small set rate of sand, irrespective of speed.
Automatic Train Operation	A system where the train is driven automatically by a control system.
Auxiliary Tread Brake (ATB)	Cast iron or composition blocks pressed against the wheel tread to remove wheel borne contamination.
Defensive driving	A cautious approach to train driving, reducing speed, braking earlier and lighter by anticipating the conditions.
Emergency Sander Device (ESD)	A trainborne sander that is manually triggered in emergency events only, which deposits a high rate of sand irrespective of the speed of the train.
Exceptional Low Adhesion	Very low adhesion conditions that could not be anticipated or expected, even if the site is a high risk Location.
LAWS	A system of data gathering and analysis to automatically identify and output locations of low rail adhesion.
Sandite / Traction GEL / TG60	A mixture of sand suspended in a water-based gel used to increase rail adhesion levels, sometimes with steel shot added for track circuit operating purposes.

Scrubbing, rail	The use of wire brushes rotating at speed to abrade material on the rail surface.
Slide, wheel	A condition occurring during vehicle braking when the wheelset is in 100% slip and is effectively locked.
Slip, wheel	A condition occurring during vehicle braking when the vehicle is moving at a speed greater than that indicated by the rotational speed of the wheels.
Spin, wheel	A condition occurring during vehicle acceleration when, due to a lack of wheel to rail adhesion, driving wheels are unable to induce the acceleration indicated by their rotational speed.
Track Circuit Actuator (TCA)	Trainborne device used to assist shunting of track circuits.
Track Circuit Actuator Interference Detector (TCAID)	Track mounted device used to operate track circuits when the TCA frequency is detected in running rails.
Variable rate sander	A trainborne sander that varies the rate of sanding depending on the brake demand selected and the speed of the train.
Vegetation Severity Index	A measure of the potential risk of rail contamination related problems along a line of route.
Water jetting	High pressure water jets used to clean debris from the running rail surfaces.

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Buffer stop collision at Chester station 20 November 2013		RAIB
Collision between two trams at Shalesmoor, Sheffield 22 October 2015		RAIB
National Industry Autumn Review 2013		National Task Force
Review of Autumn 2010 Performance	111603	National Task Force
Review of the Merseyrail and Network Rail Low Rail Adhesion Strategy	14/130512/004	Plurel
Understanding Train Control System Influence on Adhesion Performance	AEAT/RAIL/LRIS/LD820 57/RP02	RSSB

Document Title	Reference	Owner
Understanding aerodynamic influences of vehicle design on wheel/rail leaf contamination Summary Report	AEATR-ES-2006-057	RSSB
The Characteristics of Railhead Contamination Summary Report	AEATR-ES-2006-215	RSSB
ERTMS Adhesion Management - Review of ATP, ATO & ERTMS	AEATR-T&S-2003-LD43179Rp01	RSSB
ERTMS Adhesion Management - The Feasibility of Adhesion Control and Monitoring for ERTMS	AEATR-VTI-2003-015	RSSB
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A Review of Methods for Detecting Railhead Contamination	AEATR-VTI-2004-078 Issue 1	RSSB
ATOC Guidance Note – Investigation of Station Overruns and Failures to Call (withdrawn)	ATOC/GN009	ATOC
Railway applications – Braking – Wheel Slip prevention equipment	BS EN15595	CEN
Towards a high resolution 'Internet of Things' moisture detection system for railways	COF-TAR-01	RSSB
Feasibility study into non-contact ultrasonic cleaning to address the Adhesion Riddle	COF-TAR-02	RSSB

Document Title	Reference	Owner
Adhesion Riddle Feasibility Study on the use of Dry-ice for Rail Head Cleaning	COF-TAR-03	RSSB
Improving rail wettability	COF-TAR-04	RSSB
Review of Low Adhesion Research	CRF04002	RSSB
Interfaces between Control-Command Signalling and Signalling Trackside and other Sub-systems	ERA/ERTMS/033281	ERA
Guidance on Low Adhesion between the Wheel and the Rail – Managing the Risk	GE/GN8540	RSSB
Preparation and movement of trains	GE/RT8000-TW1	RSSB
Lineside Signs	GI/RT7033	RSSB
Infrastructure Based Train Detection Interface Requirements	GK/RT0028	RSSB
Guidance on Wheel / Rail Low Adhesion Measurement	GM/GN2642	RSSB
Guidance on Wheel / Rail Low Adhesion Simulation	GM/GN2643	RSSB
Guidance on Testing of Wheel Slide Protection Systems Fitted on Rail Vehicles	GM/GN2695	RSSB
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Track Circuit Assister Configuration for Rail Vehicles	GM/RT2477	RSSB
Overview of Magnetic Brakes	ITLR/T11315/001	RSSB
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Management of Lineside Vegetation	NR/L2/TRK/5201	Network Rail

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Document Title	Reference	Owner
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Arrangements Concerning the Non-Operation of Track Circuits During the Leaf Fall Contamination Period	RIS-3708-TOM	RSSB
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Impact of electromagnetic track brakes on rail infrastructure	S189	RSSB
Biochemistry of Leaves on Tracks	S235	RSSB
European Fact Finding on Adhesion: Best practice that benefits safety and performance in autumn	S250	RSSB
Biochemistry of Leaves: Chemical and Biochemical Approaches to the Removal of the Principal Components of Leaf Film	S253	RSSB
The characteristics of railhead leaf contamination	T354	RSSB
Understanding Train Control System Influence on Adhesion Performance	T545	RSSB
Understanding aerodynamic influences of vehicle design on wheel/rail leaf contamination	T546	RSSB
Minimising service disruption from failures of track circuit actuators (assisters)	T579	RSSB
Investigating a novel method for estimating low adhesion conditions	T614	RSSB
Understanding the current use of sanders on multiple units	T796	RSSB
Performance and installation criteria for sanding systems	T797	RSSB
Benefits of all-electric braking	T860	RSSB
Onboard detection of low adhesion	T959	RSSB
Enhancement of the TCA risk advisor tool to include on-track machines	T1005	RSSB

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AWG ADHESION WORKING GROUP

Document Title	Reference	Owner
Investigation into the effects of moisture on rail adhesion	T1042	RSSB
Review of the risks and opportunities from applying of sand during braking	T1046	RSSB
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Emergency One Shot Sander	RR-SAM-056	Mar 1995
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Emergency Sander Compaction Trials	RR-SAM-145	Mar 1996
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Effect of 12% g Braking on Air Consumption in Low Adhesion Conditions	RR-TRS-97-064	Mar 1997
GRIPPING STUFF	Issue 4	Apr 1997
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The Low Adhesion Warning System - 1997/98 Trial	RR-TRS-98-079	May 1998
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Adhesion Management System Developments 2006	DeltaRail-ES-2007-008 Issue 0	Feb 2007
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A Comparison of Met Office and Weather Station Data	DeltaRail-ES-2008-087 Issue 1	Jun 2008
A Comparison of ADAS Leaf Fall Indices with Service Train Wheel Slide Data	DeltaRail-ES-2008-038 Issue 1	Jun 2008
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Adhesion Management System Developments 2008	DeltaRail-ES-2009-001 Issue 2	Feb 2009

More information is available

- Railway Group Standards are available direct from RSSB's standards catalogue web site www.rgsonline.co.uk
- Network Rail standards and specifications are available from IHS Global at https:/www.ihs.com/products/uk-network-rail-standards.html
- Other RSSB material may be obtained direct from them at www.rssb.co.uk
- Many reports, including historical British Rail Research reports before 1996, are available on www.sparkrail.org
- AWG publications may be obtained via your AWG representative

A1 Summary of autumn preparations

This appendix provides a summary of preparations that should be considered to successfully help manage low adhesion.

Aspect	Overview	Section
Public Relations (PR)	Good PR is essential to ensure that customers are educated in the problems faced during the autumn. Although knowledge of 'leaves on the line' is widespread amongst customers, the press and the public at large, it is mostly ill-informed and as a result of 'bad press'.	A1.1
Operations	There are a number of train service operational measures that can be planned prior to the start of the leaf fall season to assist in controlling the effects of low rail adhesion.	A1.2
Railhead treatment programme	Successful management of railhead conditioning programmes, such as water jetting, friction modifier and rail scrubbing programmes, is a key element in managing low rail adhesion. This will be assisted by proper planning of the programme with the ability to be flexible in meeting unplanned events as they arise.	A1.3
Staff competence	The competence of staff engaged in dealing with low adhesion, particularly drivers handling their trains and signallers managing operations, is essential to reduce the risks associated with such conditions.	A1.4
Infrastructure	Management of the lineside and track conditions is essential to help prevent the contamination of rails, and to deal with contaminated rails in an effective way.	A1.5
Rolling stock	Although also subject to regular maintenance, there are a number of precautionary actions required to ensure rolling stock is ready for the autumn when poor performing equipment is likely to have a more significant impact.	A1.6

A1.1 Public Relations

Media	Use well presented facts and reasoned arguments. Make best use of company public affairs professionals, including consideration of: ▶ press releases (national and local) or video news can help get the message across; ▶ company web sites; ▶ site visits by opinion formers to see the measures being taken; ▶ posters / leaflets at stations and on trains; ▶ information displays at major stations with 'experts' on hand to help explain the facts; ▶ publication of autumn timetables.
Local authorities	It may be necessary to inform local authorities where large-scale work is to be undertaken. It may also be necessary to obtain permission to control lineside vegetation in areas of special scientific interest or in conservation areas.
Handling complaints	Complaints may arise regarding the delays and disruption to train services and from environmental concerns arising from vegetation control activities. Standard letters of response should be drawn up using the expertise of company public affairs professionals and the knowledge of engineers and operators. However, proactive action in informing people is likely to lead to fewer such complaints arising. Staff should be briefed to refer all contact at site to the public affairs department.
Lineside vegetation control	The removal of trees from the lineside is an emotive subject, even if selectively done for safety reasons. To minimise adverse reaction, the local community should be informed about what is happening, when and why. This can be done by distributing letters to nearby residents a few months prior to starting work. Careful construction of such letters is required to avoid inviting

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	objections. If necessary, local visits and meetings should be arranged to discuss the work with local residents.

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A1.2 Operations

Train formation	Train operators should consider whether it is possible to improve the use of available adhesion by introducing longer trains for critical services which may be most at risk from low rail adhesion.
Timetable	Defensive driving will reduce the brake effort demanded on approach to high risk locations and will assist in controlling the effects of low rail adhesion. This could also be achieved by a revision to the timetable to reduce the speed of trains during the autumn.
Predictive and real-time reports	Infrastructure managers and train operators will find benefit from weather reports aimed at assisting in predicting / identifying when low rail adhesion may be a factor. Other forms of predictive report, such as leaf fall rates, and feedback from drivers may also benefit. Trainborne systems can provide real-time reports of emerging conditions.
Control Centres	Control Centres should be prepared, and their systems checked out well before the commencement of the autumn programme. They will need to be reactive to the dynamic nature of the start and finish of the autumn season.

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A1.3 Railhead treatment programme

Pre-season contracts	A number of actions can be taken before the leaf fall season in order to ensure that the railhead treatment programme will be effective: ▶ nominate a 'Contract Manager' to deal with the railhead treatment contracts and advise other parties accordingly; ▶ ensure that everyone who needs a copy of the contract has got access to a copy; ▶ ensure those requiring the contract know where to obtain guidance in order to interpret the contract requirements; ▶ identify a person with responsibility to co-ordinate and manage the day-to-day railhead treatment activities in the company and issue their contact details to interested parties.
Treatment sites	▶ agreement should be reached between the infrastructure manager and train operators on the list of treatment sites and the frequency of application; ▶ the list of treatment sites should include new sites identified from the previous year and should remove sites no longer considered high risk. Data from trainborne systems capable of reporting low adhesion conditions may assist here; ▶ ensure that the high risk sites are published in the appropriate operating information available to drivers; ▶ treatment site lineside signs should be cleaned, new ones erected (reflectorised) or redundant signs removed as required.
Staff training and briefing	▶ treatment train operators should be competent in the requirements for water jetting and laying friction modifier. Consideration should be given to creating a 'core' group to maintain a high level of experience;

	▶ depot maintenance staff should be competent in maintaining the treatment train and equipment. Consideration should be given to creating a 'core' of maintenance staff to build up experience on the vehicles and equipment; ▶ staff should be briefed on the importance of the treatment train and the priority it should be given (to include roster clerks, driver / maintenance depot managers, control offices, signallers, etc.); ▶ staff directly engaged in the railhead treatment process (operators, drivers, those mixing / loading) should be briefed on the importance of correct application – for example the speed of water jetting and friction modifier laying, correct mixing of material where appropriate, where to lay and where not to lay (e.g. over point work).
Best practice	Communication with other infrastructure managers and train operators should be considered to share best practices identified from the previous leaf fall season.
Maintenance	▶ an agreed maintenance schedule should exist for the treatment trains and mixing / laying equipment; ▶ the treatment train, and the mixing, transfer and laying equipment (particularly pumps and nozzles), should receive any necessary overhaul or modifications well in advance of the treatment programme commencing to ensure they are fit for purpose. A specific shakedown test should be arranged; ▶ consideration should be given to whether the Rail Head Treatment Trains will be prepared by maintenance staff or receive an inspection by maintenance staff before the driver arrives.
Portable equipment	Ensure that portable friction modifier laying equipment has been maintained and is in full working order.

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Supplies and spares	Adequate stocks of the correct type of treatment (within its 'use-by' date) and spares for the treatment trains and mixing, transfer and laying equipment should be available.
Monitoring	▶ a process to monitor all aspects of the performance of the laying equipment, particularly whether friction modifier is actually being laid on the rails, should be in place; ▶ a publicised feedback system should be in place to allow treatment train operators to report success / failure to lay friction modifier properly, and for failure to be relayed onwards to train operators' drivers.
Testing	A live test run should be undertaken to prove that the treatment train operates effectively – preferably by mid-September.
Contingency planning	Contingency plans should be in place in case of failure of water jetting or friction modifier equipment, lack of resources or overrun of engineering work.
During the season	During the leaf fall season, the effectiveness of the railhead treatment programme should be reviewed on a regular basis. Reviews should include the train operators, infrastructure manager, treatment train contractors and infrastructure maintenance representatives, with the objective of determining: ▶ whether feedback on the success or otherwise of each treatment run is being communicated; ▶ if failure or problems are being encountered, that appropriate advice is being given to train operators and their drivers; ▶ if the treatment trains are being given a high enough priority; ▶ if weather reports and leaf fall forecasts are being obtained; ▶ whether treatment is being laid frequently enough or too frequently (note: excessive build-up of friction modifier can adversely affect the operation of track circuits);

	▶ if newly arising low adhesion sites are being addressed adequately by alterations to the treatment programme.
Post season	Following the leaf fall season, further steps can be taken immediately in preparation for the next leaf fall season: ▶ conduct a full review of the railhead treatment programme performance and its management during the leaf fall season to identify the strengths and weaknesses – trainborne systems reporting on low adhesion locations can assist in this; ▶ build the lessons learned from the post-season review into the following year's treatment programme; ▶ communicate the findings to other train operators and infrastructure maintainers as appropriate.

A1.4 Staff competence

Drivers	Ensuring that drivers are competent in train handling when rail conditions are, or are likely to be, poor is paramount to reduce the risk of an incident arising. This can be achieved by ensuring that they have received adequate training in the techniques required, including on simulators or skid pans for example, and where experience of the conditions is limited, that additional monitoring and guidance is provided. Steps to take include: ▶ identifying drivers who may require additional training associated with low adhesion either in practical handling or route knowledge; ▶ identifying drivers who require additional monitoring during the leaf fall period, for example, drivers new to route or traction type and those with little or no experience of low adhesion; ▶ considering the provision of pre-season driver briefing on low adhesion issues including the use of training videos; ▶ ensuring that drivers are familiar with the locations on their routes where low adhesion is a regular feature, particularly the high risk sites; ▶ ensuring that drivers are aware of how to anticipate where and when low adhesion conditions may arise. Drivers should be particularly aware that friction modifier cannot be laid in bay platforms unless special arrangements are made, for example, to lay it by hand; ▶ ensuring that drivers understand the requirements for reporting exceptional railhead conditions in accordance with Rule Book; what the difference between ‘normal’ and ‘exceptional’ low adhesion is; and, what is required when performing a ‘normal’ test stop at the request of the signaller; ▶ ensuring drivers are familiar with how to react to warnings of low adhesion conditions broadcast over the GSM-R train radio;

	▶ ensuring that drivers are trained and competent in the principles of defensive driving, the need to drive cautiously when low adhesion is likely, putting safety before punctuality; ▶ training should emphasise that trainborne sanders should not be relied upon and are no substitute for defensive driving; ▶ ensuring that drivers know the best braking techniques for the vehicle types they drive.
Signaller competence	▶ Signallers require a thorough knowledge of where low adhesion may be a problem in their area in order that the most appropriate action may be taken to minimise the need to stop trains in such locations; ▶ Signallers should be trained in making radio calls, including berth-triggered broadcast calls on GSM-R, to drivers to advise of exceptional low adhesion conditions; ▶ knowledge of the requirements for undertaking test brake stops on sites reported as exceptional is important, using the right type of train for the test and ensuring it is done in complete safety; ▶ signallers should know which track circuit / train combinations pose particular problems for train detection in the autumn; ▶ Knowledge of the problems faced by drivers is an ideal way to allow signallers to understand how their actions will impact the driver.
Control office staff	Staff in control offices of various types must be competent in their responsibilities for dealing with adhesion related problems in the autumn. This may range from managing information such as weather reports, interpreting data from trains, reacting to emerging issues, deciding on what restrictions to apply / remove, etc.
Rapid response teams	If rapid response teams are being used to attend localised sites to apply railhead treatments by hand, staff must be competent on how to do this and not lay excessive amounts which risks WSTCFs.

A1.5 Infrastructure

Vegetation control	The control of lineside vegetation forms an important part of low adhesion control measures. Vegetation control should commence as early as possible prior to the leaf fall season, noting that cutting back vegetation is easiest when trees are devoid of foliage, that is during the winter.
Identification of high risk sites	High risk sites should be published in the Sectional Appendix. Consider the use of fixed or illuminated lineside signs (PADS™) to warn drivers of high risk sites.
Inspection of rail contamination	Low adhesion resulting from rail contamination may be difficult to identify visually unless caused by an obvious contaminant such as crushed leaves. It is important that, in the absence of adhesion measuring equipment, staff inspecting rails are aware of the range of contaminants likely to be present.
Track circuit remote monitoring	Track circuit remote condition monitoring devices should be prepared and tested if they are being used to identify the likelihood of contamination build up leading to WSTCFs.
Track cleaning	Experience has shown that cleaning of track aprons in stations has led to deposits of oil and water on the railhead and consequential braking problems. This has occurred particularly with the use of high pressure water jets on aprons contaminated with diesel oil or lubricants from diesel traction. Methods of cleaning should be assessed to establish the effect on rail contamination and the need for any subsequent rail de-contamination.
Rail cleaning	The removal (or treatment) of rail contamination is essential to the continued safe operation of trains. Persons responsible for rail cleaning should be aware of the optimum methods for removing the various contaminants likely to be found. Incidents have occurred where an

	inappropriate method of cleaning an oil spillage has resulted in an extremely low level of adhesion.
Platform stopping position	At locations where there is a high risk of collision with buffer stops, particularly where the track is open to atmosphere, consideration should be given to providing a suitable marked stopping point in excess of the generally recognised two metres from the buffer stops. Consideration should also be given to lines fitted with 'stellite' railhead strips which reduces the size of the wheel / rail contact patch.
Opening lines previously out of use	Rails not used for periods of time can accumulate detritus as well as forming surface rust. When used for the first time, and particularly if combined with damp or wet rail conditions, adhesion levels can be significantly reduced. The risk to safety is dependent on the features of the line, but particular consideration should be given by Network Rail to advising drivers of the first train(s) over a re-opened route where signals at danger or buffer stops may present a particular hazard.
Track Circuit Actuator Interference Detectors (TCAIDs)	Consideration should be given to the installation of TCAIDs in areas where track circuit detection is a major ongoing problem during the leaf fall season despite other remedial activities. This should involve: ▶ prioritising problem areas; ▶ establishing if problem areas have been equipped with TCAID previously; ▶ establishing if the train service is primarily operated by TCA equipped vehicles; ▶ if not, establishing if the existing fleet can be exchanged for TCA fitted vehicles during the leaf fall season; ▶ if the problem areas can be operated using TCAID, establishing that sufficient modules are available – each track circuit will require four to six modules depending on length; ▶ if modules are not available from stock, establishing if a financial case can be made for new investment;

- if the line is to be TCAID equipped, establishing the installation and operating procedures from the relevant organisations;
- making sure that the batteries have been replaced on TCAIDs ready for the season.

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A1.6 Rolling stock

Trainborne sanders	Ensure that trainborne sanders are fully operative, that stocks of the correct grade of sand are available and stored under the right conditions.
Auxiliary Tread Brakes (ATB)	If ATBs are installed to assist in track circuit operation, re-instatement of isolated ATBs should be planned at an early stage to ensure they will be operational and tested prior to the start of the leaf fall season. If ATBs are not fitted, consideration should be given to fitting them by taking the following into account: ▶ are track circuit detection problems being experienced despite trackside measures? ▶ are the vehicles disc braked? ▶ how many locations are affected? ▶ is the source of the problem long-term or short-term? ▶ will friction modifier with stainless steel shot improve the performance? ▶ can disc braked vehicles operate in multiple with tread braked vehicles?
Dynamic brakes	Consider whether it is necessary to isolate dynamic braking during the autumn period.

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A2 Solutions

This appendix provides further detail on measures that are mentioned in the main text which provide solutions to the problem of low adhesion. These solutions span the realms of operations, infrastructure, rolling stock and provision of better information.

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A2.1 Operational solutions

This section describes two solutions for helping drivers improve their awareness of what happens when driving in low adhesion conditions.

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A2.1.1 Skid pan training

Skid pan training is the most realistic way that a driver can safely experience what it feels like to brake or accelerate in low adhesion, and feel the effects of systems such as WSP and trainborne sanders. There are two basics ways of setting up a skid pan: using a water / detergent mixture sprayed from the train ahead of the wheels; or using rolled-in paper tape. Paper is of course a tree-based product, as are leaves! Thin paper tape is laid onto the rail and then rolled in, it forms a very low adhesion surface when moistened with characteristics very similar to leaf film. Drivers can then experience 'real' low adhesion conditions in safety and practice their defensive driving techniques.

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A2.1.2 Driving cab simulators

Driving cab simulators have been in use for many years ranging from very basic ‘part-task’ simulators to full cab mock-ups. It is fairly straightforward to simulate braking and acceleration under low adhesion conditions within a simulator to allow the driver to ‘experience’ the effects. Whilst the simulation is not as ‘real life’ as a skid pan, driving cab simulators can be an effective form of training as the simulation can be repeated over and over again, or varied at the instructor’s wish. Printed outputs are usually available showing how the train was handled to assist in educating the trainees.

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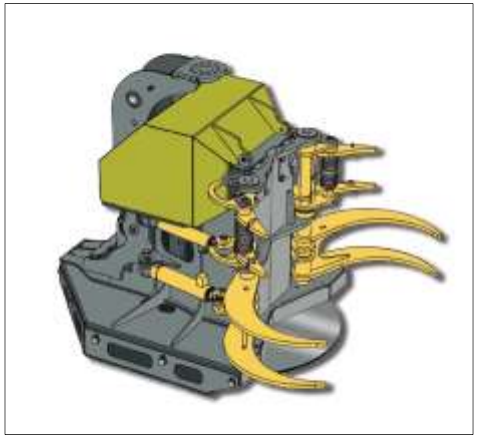
A2.2 Infrastructure solutions

This section describes a number of solutions deployed on the infrastructure to mitigate the effects of low adhesion.

A2.2.1 Vegetation management



Network Rail and their contractors use a variety of methods to clear the lineside of vegetation including power cutting equipment mounted on Road Rail Vehicles (RRVs)One device, the Bracke C16 Harvesting Head, is used to fell and collect trees and bushes and is attached to an excavator due to its long reach (7m) and lift capacity. This attachment is for the felling and collecting of small to medium trees alongside the track. It is intended to clear the 0-5m band of land adjacent to the running rail. Where possible a distance of 0-6m will actually be cleared to prevent immediate regrowth. The felling of trees is done from an on-track position.

Prior to planning the lineside clearance with this type of equipment, a site survey must be conducted to assess its suitability. This should preferably be done during the hours of daylight and at walking pace.

Trees with a base diameter greater than 250 mm will normally be marked clearly, in a position visible from the cab of the RRV, using blue tree-marking paint. Depending on the site, it may or may not be appropriate to chip wood in situ, down the bank. Otherwise, the chippings must be carried off site for disposal. On some sites, trees may be left for later chipping on a separate shift. Chipping is done in an area where it will not choke the local drainage and should be spread evenly over the ground. A mechanical grab-fed chipper / shredder should be used on the same shift so as to maximise the productivity gains of using the Bracke head.

Another interesting machine used by Network Rail is the LUF Bushfighter from Rechners fitted with a Forestry Mulcher. This tracked machine has a small diesel engine, is remote controlled and used for mulching of agricultural and forestry land and scrub. It can mulch from shrubs to a wood diameter of up to 100mm and stumps to 15 cm ground clearance.

The Bushfighter is driven into the scrub with the front cutting flap raised, which is then closed, and the machine reversed out. As the machine moves backwards the material cut down will be recycled and mulch is produced.

A2.2.2 Leaf fences

Leaf fences are another method of preventing leaves from blowing onto the track and being sucked into the wheel / rail nip. Fences may be particularly useful where trees are on adjacent land not owned by the Infrastructure Manager. Various types of fence have been employed including 2.4m high chain link fencing. Examples of this exist at Huntley (Scotland) and between Witley and Haslemere (Southern). In the latter case, the fence is on an embankment and is 3.4m high and over 800m long. Such fencing is expensive to install but may be cost effective if train delays can be reduced appropriately to offset the cost.

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A2.2.3 Removing dead leaves

ProRail, the Dutch infrastructure manager, adopts a practice of removing leaf litter from the track side using a vacuum and shredder system as shown in the adjacent photograph.

A2.2.4 Water jetting

Water jetting operates by blasting water at the surface of the running rails at high pressure to soften and dislodge crushed leaves. This may be combined with wire brushes to scrub the rails once the leaves are softened. The jetting nozzle pattern, water flow rate and nozzle alignment are critical to gain optimum performance. Current systems operate at high pressure (1500bar).

Limitations

- whilst this process has produced significant improvements in train performance, to be sustainable the treatment has to be repeated as, after the passage of as few as 200 axle passes, the leaf contamination can return;
- monitoring high pressure water jetting suggests that a residual layer of contaminant still remains after jetting (around 10 to 15 microns);
- low treatment speeds can become a factor depending on the service frequency and time of day in areas where 60mph jetting is considered appropriate – problem areas may need treatment at 40, 20 or even 10mph;
- low treatment speeds can become a factor depending on the service frequency and time of day, in areas where 60mph jetting is considered inappropriate;
- water spray on the adjacent line can lead to temporary low adhesion;
- requires significant amounts of water;
- water jetting through switches and crossings is subject to local instructions;
- attention to the set-up of the nozzles is critical.

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A2.2.5 Sand based railhead treatment

Railhead treatment solutions incorporating friction improvers such as Sandite have been in use for around 35 years and are effective at improving adhesion. One brand ‘TG60’ is used extensively throughout Britain being dispensed from RHTTs as well as static lineside TGA devices and hand-held equipment. ‘Electrogel’, an alternative product, is used in the Netherlands and Ireland and some parts of Britain.

Sand-based friction improvers consist of sand suspended in a water-based, thixotropic gel which is applied to the rails to improve wheel / rail adhesion. The mixture typically consists of an inorganic gelling agent, a stabiliser, water and standard traction sand. The gelling agent is used to provide homogeneity, the ability to be pumped and to retain the sand on the railhead. The stabiliser is used to provide a reasonable shelf life. Metal particles can be added to aid the operation of low voltage track circuits where leaf fall related problems are experienced. However, restrictions exist in using sand / metal mixes in third-rail DC electrified areas due to the risk of unwanted electrical conduction.

Sites for railhead treatment should be drawn up for each leaf fall season based primarily on the factors which dictate a location as a low adhesion high risk site. It should be remembered that the slipstream of trains and natural winds will draw leaves along a route to areas not necessarily recognised as a high risk site, and wheel borne contamination can similarly be deposited further along the route. In addition, **railhead treatment should be used to improve traction where acceleration problems occur particularly on gradients or on the exit of stations.**

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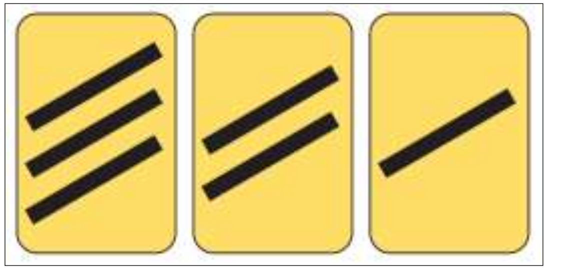

Reflectorised lineside signs can be provided as markers to tell the operator when to start and stop laying, and may be supplemented by drivers' route cards. The boards also act as a warning to service train drivers that the site is a leaf fall affected site. It is vital that these boards are erected far enough from the intended stopping point (signal, platform or buffers) to account for the likely commencement point of train braking, and it should be noted that platform stops on falling gradients are more likely to suffer problems. However, **the definition of treatment sites should be a dynamic process and should take account of the local knowledge of drivers who regularly operate the route, as they are best placed to say where they normally experience adhesion problems.** To this end, **best practice would be to move away from fixed signage to GPS control as this more easily accommodates such changes, as well as reducing the need for track maintenance.**

Sandite is drawn from on-board storage hoppers and pumped to the laying nozzles, normally located adjacent to a wheelset. Laying normally takes place at 60mph with an optimum pumping rate of 16 litres per mile. The effectiveness of the Sandite is improved by spreading it over the rail surface by a 'jockey' wheel or by the passage of the laying train's wheels. However, its effects are gradually eroded by the passage of subsequent trains, and needs re-applying periodically.

Sandite acts in two ways. Firstly, if it is laid on top of leaf film or leaf film builds up on top of it, then the passage of trains acts to grind the suspended sand and metal into the leaf film thus breaking it up. Secondly, the very presence of sand (being an adhesion improver) acts to raise adhesion levels.

Monitoring the performance of the RHTT and the application of water jetting / Sandite laying is critical. The laying of Sandite is directly monitored by visual observation or flow rate devices, and the running of the programme is recorded in quality control logs so that problems can be later analysed for future preventive measures to be introduced. It is also important that any failures to treat a site are fed back to the train operators so that their drivers can be advised. Attention must also be given to the supply chain logistics (to reduce the likelihood of running out of materials during the treatment period), staff training and facilities for loading, etc.

Post season analysis is undertaken to identify overall performance and issues that require attention prior to the next season. Network Rail undertake a comprehensive review of their treatment train performance, publishing 'league tables'. The causes of failures to treat a planned site are analysed and action plans implemented to reduce future occurrences.

Limitations

- Sandite has a limited effective time, it degrades with each axle pass crushing it onto the railhead. Studies have shown a range of 80 to 200 axle passes will deteriorate Sandite to the point where its presence on the railhead is negligible;
- in delivery units that operate without a speed regulated system, the application rate of Sandite onto the railhead varies as the delivery train slows and accelerates. In these circumstances the optimum application rate only occurs at the right train speed and speeds other than this will lead to too little or too much on the railhead.
- there have been examples where excessive laying of the mixture has led to trains failing to be detected by track circuits as the mixture dries out to form an insulating layer on the rails;
- due to the heavy and viscous nature of Sandite it is a challenging product to pump from trainborne storage hoppers via winding transfer pipes to nozzles that lay the product onto the railhead. Daily maintenance and cleaning is required, without which pipework can quickly become fully or partially blocked and seriously affect the efficacy of laying;
- being water-based, Sandite will freeze below 0ºC which could lead to blockages in laying pipes etc. This can become a problem if the leaf fall season becomes extended into the early winter by a late leaf fall;
- Sandite that includes metal shot should not be used on third-rail DC electrified lines due to its effect on degrading the conductor rail electrical insulator properties. However, it should not be necessary to use this on such lines as the traction return currents perform a role of ensuring adequate track circuit shunting;
- it should not be laid in points and crossings as it can damage the switching equipment, particularly slide chairs and clamp locks.

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Sanditing from service trains

In the Netherlands, Sanditing equipment is fitted to a limited number of passenger vehicles, each capable of laying Sandite during normal scheduled passenger operation. This has advantages in not requiring special vehicles and additional pathways, but does lead to a loss of space in the passenger environment.

The system operates using a GPS enhanced map matching technique, with automatic detection of points and switches, and remote diagnostics and maintenance facilities via 3G cellular radio. The train driver does not interact with the Sanditing at all, this is controlled automatically by reference to the mapping and GPS systems. Sandite control programmes can be uploaded remotely to the trains to alter the pattern as required.

The design includes a 700-litre storage tank and an electrical driven peristaltic pump set which lays Sandite on the track at train speeds between 5kph and 70kph. Service and refilling the storage tank is conducted during the day between the peaks, and takes 45 minutes per unit.

Speed regulated pumping equipment is used, which allows the optimum application rate where fixed speed pumping would apply too much Sandite at low speeds and too little at higher speeds.

A similar system went on trial on the live network in the West Midlands and Anglia regions in Great Britain, operating out of the Smethwick and Cambridge depots. The trials out of Smethwick continued through autumn 2017 (appendix A6 item 50).

A2.2.6 Modified road vehicles

An option for more lightly used lines, and places where running an RHTT is not practicable, is a modified road vehicle, e.g. Sand Rover. Various forms of these vehicles are in use throughout Network Rail infrastructure, delivering a range of services. This includes:

- sand dispensing;
- Citrusol / Orange Cleanse dispenser;
- leaf vacuum / shredder;
- railhead scrubbers.

These vehicles operate under T3 possession requirements. A PICOP is required to manage this together with additional Blockmen and Strapman (if in electrified area). The vehicles have an operator and a machine controller, hence a crew of four can take the possession in its entirety.

A2.2.7 Track mounted sand solution dispenser

Track-mounted static sand solution dispensers, also termed by Network Rail the 'Traction Gel Applicator' (TGA), are used primarily at remote locations where the use of an RHTT may not be efficient. Developed by Portec Rail Products and now supplied by LB Foster Rail Technologies, the dispenser consists of a cabinet with integral 150-litre capacity hopper complete with a pump and drive unit, electronic controller, charge regulator and battery. A solar panel is provided to charge the battery, which can be mounted on any side of the cabinet. The dispenser lays the sand solution on the rail via spreader bars and a hose feeder system from the cabinet. Insulated spreader bars are available for third-rail conductor rail sites. A wheel sensor is clamped to the rail on the approach side to the spreader bars. As a train passes the wheel sensor, a signal is sent to the electronic controller which activates the pump. The controller can be pre-set so that every 1st, 2nd, 4th, 8th, 16th or 32nd wheel can activate the pump. The duration of time that the pump is running can also be varied with pre-set minimum of ¼ second and then in ¼ second increments to 1½ seconds maximum.

Lawrence Industries and Portec Rail Products (now LB Foster Rail Technologies) have developed specific friction improvers for the TGA known as 'Traction Gel - U5' and 'Alleviate' respectively. The former contains urea to prevent freezing of the mix down to temperatures of -5ºC. The mixture is pumped onto the railhead and then spread along the rails by the passage of the train, up to 300m from the applicator depending on traffic density and train length.

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Limitations

- the sand-based solution has to be taken to site to be loaded into the hopper;
- the distance that the material is spread either side of the track dispenser is limited to 60-100m.
- TGAs need regular maintenance and inspections by operators trained in this task, and some parts need to be replaced every year due to wear and tear;
- the solar panels must be positioned correctly to capture enough sunlight. Cuttings can be areas of low adhesion and are also areas with fewer sunlight hours;
- TGAs are vulnerable to cold and heat – in cold weather the gel can freeze. Research by Liverpool John Moores University published in 2011, concluded that friction improvers dispensed via a TGA were only effective within a limited temperature range and were found not to provide benefit following water jetting for at least four to five hours after treatment;
- the equipment can be damaged by: engineering work, vandalism and extreme weather events (high winds, flying debris damaging the solar panels, etc);
- the equipment must be decommissioned properly at the end of the season and recommissioned before the next season starts.

A2.2.8 Hand sanding

Several forms of manual hand sanding solutions have been developed to enable rapid reaction to problems by staff located at strategic positions.

Sachets

The simplest of these are 2.5 litre sachets of Sandite produced by Lawrence Industries which can be carried to site and laid very quickly on the rails. However, the effectiveness of the application and avoidance of an excess of Sandite being laid depends on the quality of the application.

Portable Sand / Sandite Dispensers

A number of portable sand solution dispensing units are available which are loaded with a small bag of Sandite and run along the rail to dispense it at a measured rate. Various types are marketed by Lawrence Industries, Yardene, Nomix Enviro and Rotamag, as shown in the photographs adjacent and below.

Following a small number of serious WSTCF incidents caused by excessive sand / sand solution application by hand, Network Rail implemented a standard application process and training course for users. The application process involves:

- 20-zero-20 metre staggered application;
- alternate rails with constant forward motion (except DC electric third-rail territory);

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- DC electric third-rail territory, apply 20-zero-20 only on rail opposite-side to conductor rail;
- two metre 'no treatment' rule is applied at points, switches, lubricators and IBJs.

A2.2.9 Rail scrubbing

The objective of rail scrubbing is to remove the crushed leaf film from the railhead by abrading the contamination using wire brushes or scrapers. Variants of this are in use today either as portable hand-propelled units or rail mounted. On its own, rail scrubbing is not seen as a total solution but is effective when combined with other methods such as sand-based solutions. Rail scrubbing allows the rails to be cleaned back to a good base.

Operation

Rail scrubbing is sometimes carried out using converted engineer’s track machines, such as GP-TRAMMs. The wire brushes abrade the leaf debris by their scrubbing action.

In addition, there are a variety of petrol driven, hand-propelled railhead cleaners available from Geismar, Permaquip, Rotamag and Yardine.

Limitations

- cleaning rates are low. The optimum cleaning speed of trainborne rail scrubbers can be as low as 4mph, with reducing efficiency as speed rises until no benefit is gained above about 12mph;
- this slow speed generally requires a possession of the line;
- the scrubbing of rails to clean them is not a sustainable solution as the leaf contamination can return after the passage of as few as six 8-car trains, and therefore may require periodic re-application.

A2.2.10 Chemicals and organic solutions

Detergents

On occasions, rail contamination is caused by spillages of oil-based products such as diesel fuel, lubricating oil or hydraulic fluid. Fuel and oils can also be splashed onto the running rails by the action of well cleaning in stations using pressurised water cleaners. The most effective way of removing such contaminants is by washing with detergents. Detergents act to breakdown the molecular structure of a contaminant, freeing it from the surface thus allowing it to be washed away. Spreading a bucket of sand over the rails may not adequately address the situation! However, detergents themselves are used as a means of lowering adhesion levels to the range 6% to 8%, for example to conduct brake testing, hence some care is needed when using them as a cleaning agent.

D-limonene

Chemical leaf softening products have been used in Great Britain for a number of years. These generally use the organic material d-limonene to attack crushed leaf contamination on the railhead. Various suppliers market these products including 'Orange Cleanse' from Lawrence Industries, 'Natrusolve' from Genuine Solutions and 'Citrusol Orange' from Delta Hygiene and Chemicals.

These products have a citrus odour from the citrus oils contained in the mix. They are neutral PH active cleaning concentrates generally free of phosphates, caustics and glycol ethers making them environmentally friendly. 'Natrusolve' is classified non-hazardous under CPL and COSHH Regulations. The solutions are mixed with water and sprayed onto the contaminated railhead from a hand or backpack to break up the leaf mulch. The solutions themselves can create a slippery railhead so, once applied, the spray should be washed off after a minimum time period and then the railhead treated either by scrubbing it or laying sand down.

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Dimanin®

In the Netherlands, ProRail experimented with a fungal contamination killer called Dimanin® which is sprayed onto the railhead at 'shadow spots' on the rail, where moisture and algae grow.

A2.2.11 Track circuit actuator / assister interference detectors

The Track Circuit Actuator / Assister Interference Detector (TCAID), developed by BR Research in 1992, is supplied in a sealed weatherproof housing, with cables bolted to the rail web, being powered by an internal battery lasting for three months of operation. The receiver is tuned so that it responds only to the common TCA frequency. When this frequency is detected, the presence of a train is indicated and a relay inside the track mounted receiver shunts the track circuit. TCAIDs have the advantage that they are independent of the wheel / rail interface and hence will operate regardless of the amount of rail contamination present, including dry leaf contamination.

A single track circuit may require as many as 15 TCAIDs depending on local circumstances, hence a five-section track could have up to 70 TCAIDs. Being powered by battery, and containing many components and track connections, TCAID reliability then becomes a problem. Originally designed for only a short period, TCAID technology is now 15 years old.

TCAIDs have two failure modes: ‘right side’, where the TCAID shunts the track circuit when there isn’t a train on it, and ‘wrong side’, where the TCAID just doesn’t detect the train at all. TCAID wrong side failures are only revealed when the track circuit itself fails to show the presence of a train. Intermittent right-side failures can take some tracking down, as they may only occur when a particular combination of leaf contamination, weather conditions, infrastructure characteristics, and train positions coincide. These right-side failures occur when the voltages induced by one or more TCAs on a train which is on a different track circuit (and to which the TCAID should not respond) exceeds the TCAID operating threshold.

Network Rail is actively tackling TCAID reliability on several fronts. The ultimate aim, as with adhesion problems, would be to control the vegetation at source so that leaves don't get to the railhead. The TCAIDs could then be removed. Replacing track circuits with axle counters is another way to remove the need for TCAIDs (since axle counters don't rely on wheel / rail contact), but of course many leaf problems (as for adhesion) are on lesser-used routes where the financial justification for such expenditure is difficult. TCAID initiatives include:

- ensuring that TCAIDs are replaced if life-expired or unserviceable, to reduce the potential for WSTCF;
- ensuring that TCAIDs are installed in the right places. A guidance note has been produced, and the Network Rail TCAID specification RT/E/PS/11762 "Track Circuit Assister Interference Detectors" has been updated to improve and clarify the site design requirements;
- by gaining a better understanding of the mechanisms involved, progressive elimination of right side failures is being pursued, particularly track circuit 'blips' caused by trains passing on adjacent tracks;
- investigating the use of track loops as 'electronic treadles', or for detection of TCAs over a defined section of track;
- setting up a TCAID working group to assist in difficult situations. This will be the first point of contact if TCAID failures are occurring with no obvious cause or solution;
- providing better test equipment. A prototype TCAID relay monitor was successfully tested in all Regions during Autumn 2003. An improved TCAID tester was developed, to provide a simple go / no-go test, as well as being capable of simulating a TCA to check out the complete system from the rails up.

Limitations

- a TCAID provides no indication in the signal box that it has failed and is not itself fail-safe; it is therefore important that pre-season and routine testing is carried out;
- a TCAID will not detect a train with a failed TCA or a train not equipped with TCAs. **Operating instructions must consider the likelihood of unfitted trains entering TCAID equipped routes, and a TCA failure must be indicated to the driver who can then follow appropriate procedures in conjunction with the signaller;**
- TCAIDs are not suitable for some types of track circuits;
- maintenance is labour intensive;
- they cannot be used on steel sleepers.

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A2.3 Rolling stock solutions

This section describes a number of solutions deployed on rolling stock to mitigate the effects of low adhesion.

A2.3.1 Magnetic track brakes

MTBs are used extensively in mainland Europe. They are also used in GB on Nexus (formerly the Tyne and Wear Metro) and Manchester Metrolink which both operate in part over Network Rail managed infrastructure. All other GB tramways including Blackpool Transport, Centro (Midland Metro) and Sheffield Supertram use MTBs on their networks. On the other hand, the GB mainline railway has never used MTB although it has in the past experimented with them to determine benefits. Tests were undertaken on a Mark III vehicle bogie and on the BR Research Tribometer train but the results were not positive, so adoption was never taken up. Two decades on, following a benchmarking exercise to compare MTB against existing low adhesion control measures, AWG commissioned Interfleet Technology (now SNC Lavalin) to investigate adoption on existing rolling stock looking into the feasibility and benefits.

Three classes of vehicle, and hence bogie types, were studied to represent the majority of the GB fleets:

- Class 319 4-car dual voltage EMU;
- Class 158 2-car DMU;
- Class 350 4-car EMU Siemens Desiro.

Key findings were:

- the most effective location for the MTB would be on the leading bogie, but that this was not possible on the fleets examined due to other equipment occupying the space such as ATP, TPWS, AWS, train stops, third rail shoegear and TCAs;
- using MTB for service braking was ruled out because of the high pole shoe wear rate and associated high maintenance costs – a set of MTB shoes would be worn out after just six weeks compared to the more normal five year plus life.

European Experience

MTBs have been in use in Europe for a number of years. They were mainly introduced to increase braking performance to allow an increase in line speed within existing signal spacing. On clean, dry track with an adhesion coefficient of 0.12, a pair of track brakes fitted to one bogie can produce up to 24kN of brake effort. However, this is susceptible to reduction on wet or contaminated rail and could reduce to 40% of this value. NS, the Dutch rail operator, identify the advantages as:

- roughening / cleaning of the rail (also for following trains);
- improved performance of the normal brakes;
- improved train detection.

They identify the disadvantages as:

- uncomfortable brake force when activated;
- wear of railhead;
- a speed dependent brake force;
- safety acceptance (variant / geography dependent);
- high maintenance costs.

In 2014, RSSB conducted a knowledge search into the impact of MTBs and eddy-current track brakes (ECTB) on rail infrastructure (S189). Key findings were:

- MTBs are not wholly independent of adhesion conditions due to the direct interaction with the railhead and retardation force produced via mechanical scrubbing. On the other hand, ECTBs are independent of the railhead, and as such, braking force is not dependent on the rail conditions. Further, as braking does not depend on a friction coefficient, this has the advantage of reduced braking noise, wear and maintenance costs to the rail;
- repeated use of MTB, especially at high speeds, is likely to incur damage to the railhead, which will likely require inspection of the track and possible replacement of the rails following the use of MTBs. MTBs are though considered effective for use during emergency braking due to the improvement in braking found from the scrubbing effect in low adhesion conditions;

- compatibility issues with ECTB were raised along with rail heating and pulling effects. For instance, ECTBs may not be effective for use during low speeds and need to be switched off to ensure the train weight stays within the axle loading limit of the track structure.

In 2016, RSSB took this work further by considering the technical compatibility and economic potential of MTB on GB mainline rail (T1099). Key findings were:

- no significant incompatibilities between trains equipped with MTB and the GB mainline infrastructure that could not be mitigated;
- several specific conditions were identified however (e.g. less robust sections of track), in which further work was advised and where MTBs should be used only in emergency braking scenarios and not repeatedly at the same locations – the process for checking infrastructure compatibility was tested on a case study route (St Pancras to Corby);
- an economic case indicated support for the deployment of MTB as standard on new rolling stock builds in GB (£3.5m/year benefits on costs of £9.8m), however, it was recognised that this finding would not meet some business cases for investment;
- uptake of MTB could improve braking performance giving drivers more confidence during low adhesion conditions, in turn reducing SPADs and station overruns.
- recommendations to be used when preparing a standard to enable the introduction of MTBs to GB mainline rail infrastructure.

The project therefore endorsed the development of a new Railway Group Standard to enable the introduction of MTBs to GB mainline rail.

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A2.3.2 Wheel Slide Protection systems

Wheel Slide Protection (WSP) system requirements

All mainline rolling stock now needs to comply with the Technical Specification for Interoperability relating to locomotives and passenger rolling stock (LOC&PAS TSI), which in turn requires WSP systems to be compliant and certified to the European standard BS EN 15595 "Railway Applications – Braking – Wheel slide protection". There are no GB specific railway standards for WSP equipment, a general requirement for minimising the stopping distance extension due to WSP activity being contained within the Railway Group Standards for train braking.

BS EN 15595 covers the construction and testing of WSP equipment and specifies the acceptance test conditions for WSP, which involves track testing of vehicles on detergent-wetted track. Experience in GB with WSP equipment that has been approved **only** by the track testing method has not been good, with significant wheel damage problems and poor low adhesion braking performance. This has been attributed to the test method not being representative of real conditions which can be much lower and variable than the test criteria. Hence, modern systems for operation in Britain are usually tested against the standard WSPER test as well as the BS EN 15595 WSPER test.

The concerns resulted in the following 'National Forward' being added to the BSI published version of the standard:

The UK Committee would like to emphasize that the requirements contained in this standard are not necessarily representative of all the performance requirements, or the suitability of Wheel Slide Protection systems for all low adhesion service conditions likely to be encountered in the UK. In particular:

(i) The brake mode designations referenced in this standard (see Subclause 3.3) for passenger and freight train operation are derived from continental European practices and are not used on the UK network.

(ii) The type test programme for coaches, wagons and trainsets set out in Tables 3, 4 and 5 of this standard assume that the vehicles will be equipped with a level of braking performance that are higher than is needed to operate over the UK network.

(iii) The testing of the WSP as set out in this standard assumes levels of adhesion will generally be in the range 0.06 to 0.08 (see Subclause 5.3.3). UK experience has shown actual adhesion levels can be significantly lower than this range.

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The mandatory testing methodology included in this standard is based on the use of artificially generated low adhesion conditions (e.g. detergent solutions or equivalent). Previous UK experience has shown that WSP systems, tested using such artificially generated low adhesion conditions, have required additional optimization of their performance to satisfy the lower adhesion levels typically encountered on the UK infrastructure. Further optimization of WSP systems can be conducted by using simulators as set out in Annexes A and B of this standard. This approach has proved to be very effective in achieving the required level of WSP system performance on UK infrastructure, in respect of optimized low adhesion braking performance and minimized wheel and rail damage.

In order to minimize the risk of avoidable damage to the UK railway infrastructure, WSP systems fitted to rolling stock intended for operation over the UK railway network should be optimized for the lower levels of adhesion typically encountered on the UK infrastructure.

AWG commissioned a 'best practice' document – "WSP Acceptance & Performance: A Guide to Best Practice" – to provide guidance on WSP simulation testing. The guidance provides a generic test specification, proposes a test approach and fulfils the requirements of the CEN standard and current Railway Group Standards**. AWG recommends WSP manufacturers and vehicle builders continue to use a simulation approach, using naturally occurring variable low adhesion conditions to produce a better performing WSP under real low adhesion conditions.** This has subsequently been published in a Railway Group Standard guidance note, GM/GN2695 "Guidance on Testing of Wheel Slide Protection Systems Fitted on Rail Vehicles". This document is intended to assist train operators, equipment suppliers, train manufacturers and procurement organisations involved in specifying WSP equipment for rail vehicles intended for operation on Britain's mainline network.

The recommended simulator test specification includes a programme of rig tests; measurement and pass / fail criteria; tests using naturally occurring variable adhesion profiles; sustained low adhesion tests; high speed (>160kmh) tests; and optional tests for sander systems, dynamic braking systems and peripheral outputs to other trainborne systems. Only by testing WSPs under such a broad range of conditions, and at various vehicle configurations such as with simulated new and worn wheels, will the WSP's true performance be identified, thus allowing the supplier an opportunity to engineer out less than optimal performance before experiencing the results for real when changes would be much more costly.

Optimising WSP

Modern WSP systems are software controlled, utilising 'two stage' (adaptive) dump valves. These systems have the advantage of having fast response rates, low air consumption and the ability to be 'optimised' through software changes to suit the specific vehicle and range of rail conditions. The WSP can be used for providing inputs to other systems such as speedometers, trainborne sanders and low adhesion identification / warning systems (section 3.5.6), which all require good WSP performance to function accurately. Optimising the performance of the WSP for the vehicle type is therefore an important part of maximising system performance. For newer systems, the WSP control function is now frequently integrated within the electronic Brake Control Unit (BCU). A modern train braking system may also share information between BCU control units along the train to better manage the low adhesion performance.

RSSB guidance note GM/GN2695 “Guidance on Testing of Wheel Slide Protection Systems Fitted on Rail Vehicles” provides advice on WSP testing and optimisation. Section 2.4.1 recommends that supplementary WSP performance testing should be considered for the following reasons shown adjacent.

a) To optimise the behaviour of the WSP system for the adhesion characteristics of the GB mainline network.

b) To demonstrate that the optimised WSP system in low adhesion conditions will:

   i) Minimise the extension of stopping distance.

   ii) Minimise wheel tread damage.

   iii) Minimise air consumption.

   iv) Minimise railhead damage.

   Note: The priority assigned to each of the factors is dependent upon the type of rail vehicle on which the equipment is intended to be used, and the design performance of the rail vehicle in terms of the operation and maintenance that is agreed between the railway undertaking, train manufacturer, equipment suppliers and procurement organisation.

c) To evaluate the implications of other factors that could affect train braking behaviour in low adhesion conditions, for example sanding, dynamic brake.

d) To monitor and evaluate the behaviour of the signals generated by the WSP system that influences other train systems in low adhesion conditions, for example the traction interface, speedometer, auto-sanding, speed switches.

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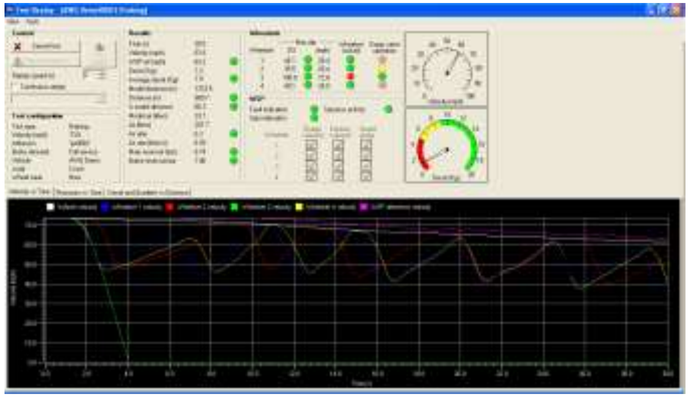
Deutsche Bahn – ESG operate a simulation facility known as the Wheel Slide Protection Evaluation Rig (WSPER). This is a laboratory-based test facility which subjects the WSP / BCU to a wide range of 'real' low adhesion conditions measured on GB track by the former British Rail Tribometer Train. This technique is reliable and repeatable and has proved very successful with WSP manufacturers and owners at home and abroad for optimising WSP performance.

The tests can be repeated, allowing the WSP control system to be adjusted until optimum performance is obtained. The majority of Britain's new rolling stock have WSP systems which have been optimised on this evaluation rig and as a result perform very well when compared with non-optimised systems.

The picture below shows a typical output from WSPER showing how the wheelsets perform under the control of the WSP for a particular adhesion profile.



As the frequency of train operation increases to meet passenger demand, the operational constraints placed upon the railway will shorten the headway between trains and as a consequence, foster more automation. To manage safety and avoid operational delays in these circumstances, it is essential to qualify how the reliability and integrity of an automated braking stop is influenced by low adhesion.

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Some train operations such as ATO and ETCS require guarantees of performance within a specified range (distance). Increasing passenger numbers has also led to longer unit formations becoming more common along with distributed sanding and ATO operation. In such circumstances the traditional 'single car' test simulation method is unlikely to remain sufficiently representative. To address these requirements, multiple vehicle simulation facilities such as the DB ESG WSPERmv (multiple vehicle) have been developed. WSPERmv has the capability of testing up to five vehicles simultaneously but with an architecture that permits longer trains to be modelled with distributed sanding and ATO operation, but also permits assessment of BCU systems with information sharing between the vehicles. This 'whole train' simulation approach is likely to become the 'standard' approach for simulation testing in the future.

Upgrading older WSP Systems

Upgrading older WSP systems to modern, optimised microprocessor controlled WSP systems with adaptive control, can deliver the following benefits:

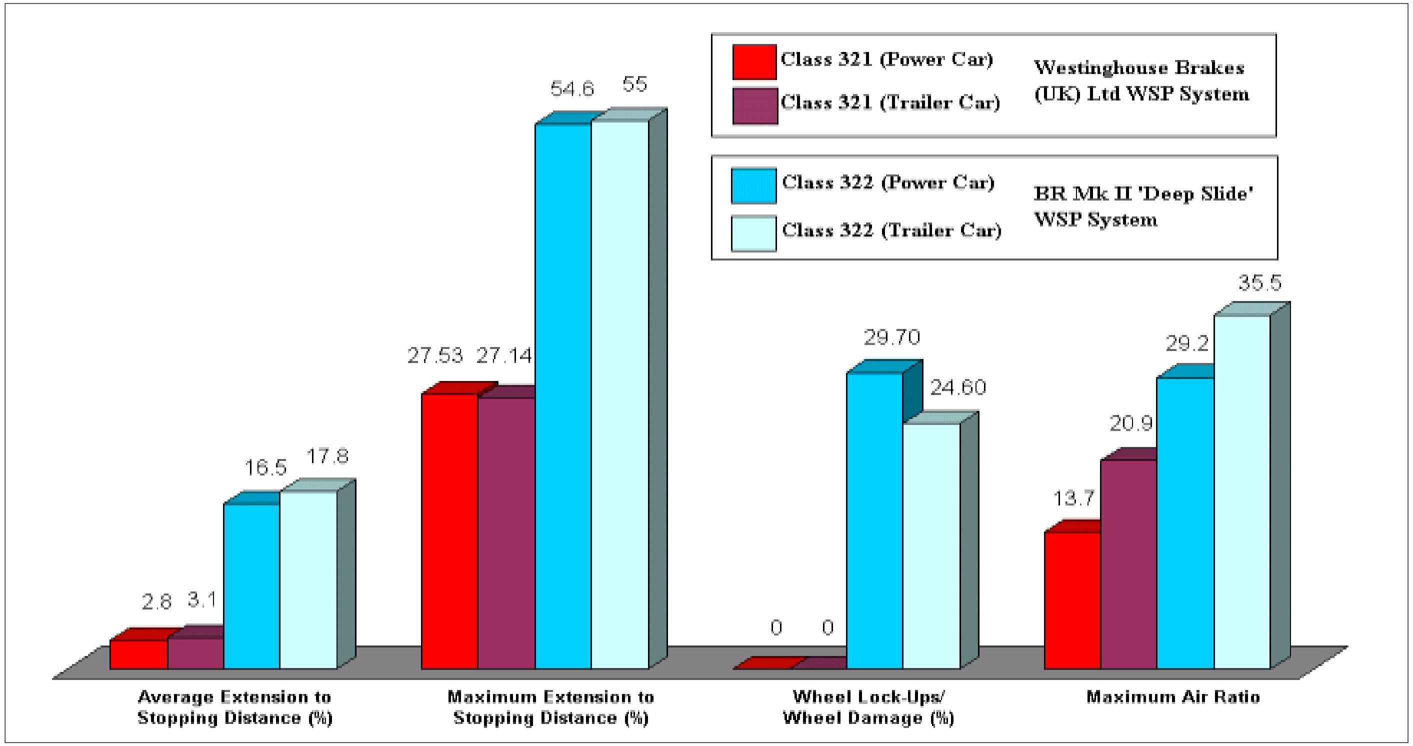
- improved safety as a modern WSP system can minimise the extended stopping distances seen with older 'BR' systems;
- improved ride quality through reductions in wheel flats, noise and vibration;
- reductions in track damage;
- a reduction in operating costs through reduced train delays, fewer operating incidents and reduced maintenance requirement (no probe gap-setting, on-board diagnostics etc.);
- increased vehicle utilisation through reduced vehicle downtime and improved reliability;
- potentially increased line capacity through more reliable reduction in stopping distances.

AWG developed a cost benefit analysis spreadsheet that allows train operators and rolling stock owners to see if there is a case for replacing older WSP systems with modern 'state-of-the-art' microprocessor-based ones. The cost of replacement could be funded by the significant reduction in wheelset maintenance costs.

This spreadsheet was used to good effect by Transys Projects Limited (now Kieppe Electric) with Westinghouse Brakes (now Knorr-Bremse) to justify the upgrading of older 'BR' WSP equipment on certain fleets, and Knorr-Bremse has since produced a retro-fit WSP upgrade package.

Managing Low Adhesion

The graph below shows the comparative performance seen on the WSPER for Class 321/322 units which have been upgraded from Mark II BR WSP to Knorr-Bremse microprocessor controlled WSP.



The graph shows significant performance improvements and reductions in wheel damage:

- the average stopping distance extensions were reduced from around 17% to 3%;
- the maximum stopping distance extensions were reduced from 55% to 27%;
- wheel locking / damage was eliminated from a base of 24% - 30%;
- maximum air consumption was reduced from 30% - 35% down to 14% - 21%.

It would be expected that other makes of modern microprocessor controlled WSP systems would achieve similar levels of improvement.

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The above applies to upgrading older WSP systems, however there are also benefits from installing new WSP systems on tread braked vehicles that have previously not been fitted with WSP. For instance, Greater Anglia has recently fitted their Class 156 DMU fleet. Experience during their first autumn in 2017 has been very good with a marked reduction in wheel slide incidents, thereby protecting the wheelsets, and delivering a significant bonus to the operator.

Limitations

Although modern optimised WSP systems are very effective at maximising the use of available adhesion, they are still limited in their effectiveness by the adhesion levels present:

- Unlike adhesion improvers like sand, they cannot significantly increase adhesion, but the conditioning effect can improve overall performance, particularly on longer trains.
- WSP systems can exhaust large quantities of air via dump valve operation when adhesion levels are exceptionally low. This may become a factor in braking performance if high braking rates are demanded and air capacity is limited. AWG have reviewed the effects on WSP operation on multiple unit air consumption, particularly for vehicles with enhanced emergency braking, and a report is available “Effect of 12%g Braking on Air Consumption in Low Adhesion Conditions”. On modern multiple units the design air capacity is informed by air consumption data from simulation rig tests of worst case adhesion conditions, whilst recognising that air also has to be supplied to sanding systems and it has to be supplied at the same time. Hence, low adhesion braking performance should not be compromised by inadequate air capacity.

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A2.3.3 Trainborne sanders

Trainborne sanding systems have proven effective at reducing the risk of low adhesion (appendix A9). This section of the manual outlines the different types of sander that are available, requirements and good practice in using them.

AWG ADHESION WORKING GROUP

A2.3.3.1 Sander requirements

European Standards / Specifications

The European Union Agency for Railways has issued a specification (Index 77) as part of the Technical Standard for Interoperability (TSI) for the Control Command Signalling sub-system (CCS). The document, ERA/ERTMS/033281 "Interfaces Between Control-Command and Signalling Trackside and Other Sub-systems", defines the interoperability requirements that are applicable at the interface between the trackside CCS and other subsystems (mainly, but not exclusively, rolling stock).

The specification is limited to requirements related to compatibility of train detection systems with other subsystems. It requires that train detection systems shall be designed in such a way that they are able to detect a vehicle or consist under the conditions specified. Of significance are the requirements for sanding, which are reproduced below:

3.1.4. Use of sanding equipment

3.1.4.1. Maximum amount of sand

Harmonised parameter: The allowed amount of sand per sanding device within 30s is:

1. *For speed v < 140 kmh; 400g + 100g*
2. *For speed v > 140 kmh; 650g +150g*

The number of active sanding devices does not exceed the following:

3. *For multiple units with distributed sanding devices: the first and last car and intermediate cars with a minimum of 7 intermediate axles, between two sanding devices that are not sanded. It is permissible to couple such multiple units and to operate all sanding devices at the coupled ends.*
4. *For loco-hauled trains:*
5. *For emergency and full service braking: all available sanding devices*
6. *In all other cases: a maximum of 4 sanding devices per rail*

This parameter shall be taken into account jointly with 3.1.4.2 (Sand Characteristics).

Justification: Sand is applied to the tracks to improve braking and traction performance. Sand can create an isolating layer between wheels and rails increasing the contact resistance, with risk of not detecting trains on tracks equipped with track circuits.

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3.1.4.2. Sand characteristics

Harmonised parameter: The characteristics of sand applied to the tracks are: [open point]. This parameter shall be taken into account jointly with 3.1.4.1 (Maximum amount of sand). This parameter is to enable the margins related to contact resistance between wheels and rails to be taken into account for the use of track circuits.

Justification: The composition of the sand which is used is relevant for the risk of not detecting trains on tracks equipped with track circuits.

The Agency have clarified the above as follows:

- rolling stock characteristics compliant with Index 77 criteria shall be recorded in the rolling stock register;
- rolling stock declared compliant with Index 77 criteria can operate on infrastructure declared CCS TSI train detection compliant without further assessment;
- the Index 77 criteria is not mandatory for the design of rolling stock sanding systems;
- alternative rolling stock sanding criteria are permitted subject to the agreement between the IM and RU.

Index 77 is not a mandatory requirement for sanders; it is the specification for on train sanders if a rolling stock or sander manufacturer wish to declare them as an interoperable subsystem. For GB, our Notified National Technical Rule is Railway Group Standard (RGS) GM/RT2461 “Sanding Equipment”. This is mandatory and exceeds the requirements of Index 77.

Railway Group Standard

In light of the above, Railway Group Standard (RGS) GM/RT2461 "Sanding Equipment" sets out requirements for vehicle mounted sanding equipment that can be used to mitigate low railhead adhesion conditions, the specification of sand for use in that sanding equipment and guidance on the design and operational use of sanding equipment. Originally issued in 2001, the standard was re-issued in 2016 to reflect the findings of RSSB research projects T796, T797 and T1046. RSSB is currently carrying out trials to investigate sand laying rates and this may result in further changes to this standard (T1107).


Sanding Equipment

A2.3.3.2 Types of sander

Three main sander systems have thus far been used on Britain's mainline railway. The following gives an overview of them and more detail is available in Railway Group Standard GM/RT2461 "Sanding Equipment".

Emergency Sanding Device

The Emergency Sanding Device (ESD) is based on fire extinguisher technology. The objective of the ESD is to improve adhesion conditions when facing an emergency. This includes Signals Passed at Danger (SPADs), collisions and other equally serious incidents. However, ESD is not intended for operation when incidents involve station platform overruns (unless the platform happens to be a terminus platform or bay platform) and provides no benefit to improving train acceleration.

There is also an increased risk of the train, or a following train, being undetected by track circuits following activation of the ESD, as the sand discharge rate is relatively high. Specific operating rules are employed to guard against this risk. More recent trains fitted with the ESD have the sander installed before axle 3, rather than axle 1 on earlier fitments. The sander is also inhibited at low speeds. Both these changes reduce the risk to track circuit actuation. However, because of the track circuit actuation issues, ESD have not been permitted on new build rolling stock since 2001 due to the publication of GM/RT2461.

The ESD has obvious limitations and trains fitted with this device are normally required to be taken out of service if the ESD is used. To overcome this limitation, ESD fitted fleets may have a reserve sand cylinder, a 'two-shot' system to keep the train in service, unless of course the second shot is used. The system requires drivers to manually select the reserve sand supply after the initial supply has been deployed.

The preference when choosing sanding systems is now for the more sophisticated systems described below. In their report into the buffer stop collision at Chester station in November 2013, RAIB recommended that operators of Class 220 and Class 221 units should fit sanders that automatically deposit sand when wheel slide is detected during heavy braking. The vehicles involved in the collision where fitted with ESD.

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Automatic Sanding Device – braking

The objective of the Automatic Sanding Device (ASD) is to improve adhesion levels for any type of adhesion-related incident, including station platform overruns and when accelerating.

The system consists of a sand hopper which feeds sand to a mixing valve which in turn supplies the sand via a delivery pipe to the wheel / rail interface. The mixing valve requires an air supply, which is taken from the unit's main reservoir. The air supply is controlled by an EP valve, which is activated when the WSP system operates, provided the driver has selected an appropriate brake step. It is normal to enable sanding in brake step two and above with the ASD, or equivalent analogue brake settings. For tread braked units, the sander is triggered manually using a button on the cab driving desk.

The ASD on disc braked units requires an efficient WSP system to ensure optimum operation. Sand is ejected at a nominal rate of 2kg/min. Some installations make use of a higher sanding rate than the nominal 2kg/min when at higher speeds, as the mandated maximum rate is specified as a sand density per linear metre of track, 7.5g/m. The guidance sanding rate of 2kg/min relates to a train travelling at 10mph, but at 60mph this sanding rate equates to only 1.24g/m sand density, hence there is scope to significantly increase the sanding rate with speed.

The performance improvement expected from an ASD depends on many factors, including train length. Tests and service experience have shown that the system can improve adhesion levels on a two-car Class 165 unit by around 3%g equivalent braking performance from exceptionally low levels. Although this improvement is less than that achieved by ESD, it is consistent with using step two braking on modern units, and in excess of that necessary for early braking using step one.

Limitations

- ASD does not restore exceptionally low adhesion conditions to the levels required to support Full Service braking;
- assuming that drivers brake using step one or two during low adhesion conditions, ASD requires the driver to recognise that an emergency is arising and select an appropriate brake step early enough to receive the full benefit;
- some systems have included maximum sanding time limits or low speed cut off thresholds to preserve sand supply, limiting potential benefits;
- quality of the WSP algorithm – if the wheels lock, WSP activity will cease. If this happens during defensive driving in brake step one or two, sand will then be inhibited when the driver selects step three or emergency;
- reliability of the WSP – again wheels may lock due to WSP failure and sand will be inhibited;
- suitability of the WSP output signal which is used to provide a 'low adhesion' warning signal to the sander control system. There is no specification for the functionality of this output, but it must be appropriate for sander control.

Although not strictly a limitation of the system, reduced sand output is an issue that must be recognised. Whilst 2kg/min/rail is recommended as the maximum allowable to protect track circuits at low speed, it must also be understood that insufficient sand will reduce the safety and performance benefits. Reviews of sander performance have shown many operating at around 1kg/min due to maintenance issues e.g. blocked / sagging hoses, blocked sand box breathers, poor nozzle alignment, wet sand and component wear, e.g. orifice plates (RSSB Research project T796 "Understanding the current use of sanders on multiple units for further details"). AWG data has predicted a 100m reduction in braking distance from 50mph when the static sand flow rate was increased from 1.5kg/min to 2kg/min. Sand boxes must also be kept topped up **at all times** of the year.

Variable Rate Sanders

The mandated maximum sand density of 7.5g/m (RGS GM/RT2461) equates to the recommended maximum sand flow rate of 2kg/min/rail at approximately 10mph and thus fixed rate 2kg/min sanders are usually suppressed from automatic operation at speeds below this.

The flow rate originates from tests conducted on behalf of the BR Board by BR Research on the ASD fitment for Thames Trains Class 165/166 fleets in 1995. The results of those tests indicated that sand laid at the above rate might cause track circuit actuation problems at speeds below 10mph. However, a train fitted with such a sander will decelerate at a sufficiently high rate at low speed, even in very low adhesion conditions, so that only a very short length of rail is affected. Track circuit actuation is then maintained at both the front (unsanded axle) and the rear of the train.

The critical sand density above which track circuit problems may occur is deemed to be 7.5g/m on the railhead (based on the above 2kg/min applied at 10mph). Subsequent tests, and service experience, have shown that this figure is probably pessimistic. It follows that it is possible to apply more sand at higher operating speeds and remain within the safe envelope of the critical sand density criteria. Thus, a sand application rate of, say, 4kg/min at operating speeds above 20mph should not cause a problem to track circuit actuation but would offer significant performance benefit.

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Consequently, the variable rate sander was developed and is now available from several manufacturers. This is a form of ASD capable of sanding in both traction and braking, but also able to deliver sand at a variable rate dictated by the brake demand and train speed. As with ASDs, reduced sand output due to inadequate maintenance is an issue that must be recognised, however there are many advantages:

- the amount of sand delivered can be varied according to driver demand giving the ability to achieve close to the demanded braking rate under all operating conditions;
- the maximum sand delivery rate is higher, thereby providing a greater increase in available adhesion, giving the potential for improved performance at higher speeds;
- because the rate at which sand is delivered can be reduced, the density of the layer of sand applied to the railhead can be controlled, thereby reducing the risk to track circuit operation particularly at low speed;
- the ability to minimise the risk to track circuits also enables sand to be applied in all brake steps without compromising track circuit performance, providing superior overall braking performance;
- sand is delivered in traction under driver control, and this can be configured to also provide sand at a variable rate according to operating speed, enhancing traction performance in low adhesion;
- the increase in adhesion offered at all levels of brake demand means that the risk of wheel damage will be significantly reduced, leading to reduced wheelset maintenance costs.

There are a number of parameters that variable sander control systems use to adjust the sanding flow rate such as the train speed, brake demand, achieved level of brake pressure, etc.

More recently, Variable Rate Sanders have moved on from the ‘single stage sander’ described above to provide a greater range of sanding rates. These sanders can have a series of valves that can switch in different pressure levels of air flow (set by regulators) into the sand ejectors, hence giving sand delivery rates at different stepped levels. Others have a pressure control device to provide an analogue variable pressure into the sand ejector, thus providing a completely variable sand delivery rate. Some manufacturers also use an electric device to convey the sand, thus allowing them to provide a completely variable delivery rate.

Further performance improvement can be gained from intelligent sanding systems that are able to vary the rate of sand from distributed sanders in response to the level of adhesion detected. For instance, the system used on London Underground's 'S Stock' employs a complex algorithm running in the brake control units that monitors the level of slip, number of axles slipping, duration of slip, percentage of brake cylinder pressure achieved against demanded level, and a number of other characteristics to determine when to operate the two sanders available in each direction. Each sander is a two-stage unit so in all the train effectively has a four-step sander. The control system is able to vary the sand flow at each location in order to get the most efficient use of the sand for the adhesion available.

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A2.3.3.3 Performance improvement

Trainborne sanders have demonstrated an improved braking performance under low adhesion conditions. The RAIB report into the collision at Exeter St Davids station in January 2010 identified lack of sanders as a contributory factor in the incident.

The level of performance differs depending on the system employed. Systems designed to lay significant quantities of sand like the Emergency Sanding Device are capable of increasing adhesion levels to that required for emergency braking but have a higher risk of affecting track circuit operation. Systems such as the Automatic Sanding Device, operating at its designed 2kg/min flow rate, can achieve up to a 3%g improvement to the underlying braking rate on low adhesion.

Constraints and Limitations

Infrastructure effects

The main perceived problem with applying sand to the railhead is the potential risk to the operation of track circuits and, to a lesser extent, damage to track mounted equipment. Experience with locomotive sanders has shown that liberal use of sand can allow vehicles to 'disappear' from track circuits, so much so that light locomotives with automatic sanders are often required to run with their automatic sanders switched to manual or isolated. Secondary to this, excessive use of sand can get into point work and other lineside equipment causing premature wear and failures. Finally, concern has been expressed over the potential to increase the rate of railhead wear and induce Rolling Contact Fatigue (RCF).

These factors were extensively studied by the Manchester Metropolitan University Rail Technology Unit for Network Rail through an in-depth monitoring exercise. The six-month study identified no major impact on either vehicle or infrastructure condition that could be attributed to trainborne sanders. The study team noted that there could be much longer-term effects but considered that the existing track and train maintenance regimes should be largely sufficient to control the risk of such deterioration. The team considered that the study had provided adequate evidence that sanders compliant with RGS GM/RT2461 didn’t result in a deterioration of the infrastructure or vehicles over one season, and gave confidence that the continuing use would not result in unacceptable deterioration over time.

In 2015, RSSB built on these findings in a research project (T1046) which compared the safety implications of how the increased use of sanders (i.e. already fitted but suppressed) would affect the:

- potential increased risk associated with wrong side track circuit failures (WSTCFs), offset by;
- reduced risk from adhesion-related signals passed at danger (SPADs).

The effect on train performance was also assessed and key findings were:

- over a 10-year period, 54 low adhesion related SPAD incidents occurred involving multiple units;
- over the same period, 3% of WSTCFs were attributed to sand contamination with the rest largely being attributed to other forms of railhead contamination, mainly leaf fall and rust;
- this suggests that the fitment of reliable sanders and the use of enhanced sanding capabilities (un-suppressing sanders on trailing multiple units) could deliver a significant reduction in the frequency of low adhesion SPADS – the reduction in SPAD risk was at least 170 times greater than the current risk associated with WSTCF caused by sand contamination;
- the analysis of autumn delay incidents in 2012 and 2013 **suggests** that un-suppressing sanders on trailing multiple units could raise the adhesion levels to **support** a 3%g improvement in brake performance and reduce the number of delay minutes by 58%. Whilst the study could not guarantee a 3%g braking enhancement in absolutely all cases from such un-suppression, it would make a significant journey towards this. The study also **suggests** that delay minutes could be reduced by a further 6% with the development and fitting of enhanced sanders capable of supporting a 6%g improvement in brake performance, however a declared route to this will not be available until T1107 is published in early 2018.

Sanding rate

- The sand flow rate is generally considered to be 2kg/min which equates to laying sand on the railhead at a rate of 7.5g/m at 10mph. Increasing the sand rate would provide additional low adhesion braking benefit, but increases the risk of track circuit detection failure. The sand delivery rate on some modern EMUs fixed rate sanders has been increased to 3kg/min without any evidence of track circuit problems. However, Variable Rate Sanders (section

A2.3.3.2) are clearly more efficient as they allow the higher rate to be delivered at high speeds, but reduce delivery at low speed so the maximum delivery per metre is not exceeded.

- Recent developments have enabled the rate of sand application on ASD to be increased to 3kg/min whilst still maintaining the 7.5g/m sand density at higher speeds, and at 3kg/min for traction sanding. This has the advantage of maximising the sand laying at higher speeds.
- Further developments have enabled sand to be laid by ASD systems along the (multiple unit) train as well as at the front vehicle. Class 377/5 units are built such that the sander on the leading vehicle of the second unit can sand if the sand box on the first unit has dropped to 20% full or has a fault. It is noted that there will be at least 18 axles following the second sander.

The question remains as to what is the best sanding rate that maximises adhesion without compromising train detection. In 2015, service experience and developments in modern sanding systems, RSSB reviewed the existing sanding parameters in GM/RT2461 to see if train performance could be improved in low adhesion conditions (T797). Key findings were:

- the existing criteria was based on a specific set of tests performed on two and three car diesel multiple units;
- most countries did not define any criteria for the installation and operation of sanding systems;
- laboratory testing assessed the dynamic performance of sander delivery systems to determine the optimum alignment relative to the wheel/rail interface and showed that size and shape of the sanding hose, use of a nozzle, and positioning of the sanding hose had an effect on sanding performance. For instance:
- fitting a plain nozzle to the end of a wide bore hose was found to effectively direct and increase the amount of sand passing through the wheel/rail interface;
- while a narrow bore hose improved the accuracy of sanding performance, it required a significantly higher air pressure to achieve the same flow rate compared to the wider hose;
- positioning the hose was also found to be optimised when the sander is longitudinally aligned with the centre of the wheel, set at a shallow angle to the rail (10° to 15°) and aimed just in front of the wheel and rail contact.
- insulation and dispersion testing concluded:
  - dispersion rates of 7.5-11.5g/m for restoring wheel / rail contact across multiple axles (up to seven);

- dispersion of sand at a rate equivalent to 5.5g/m was shown to increase adhesion but inconsistently, possibly due to the low density of sand creating patches where no sand was present;
- when sand was laid at 7.5g/m, the adhesion level **in the sanded area** increases to approximately that of clean dry rail; however higher rates did not offer any further improvement in adhesion.

▶ increased performance in low adhesion could be achieved through distributed active sanding systems along different arrangements of multiple unit formations.

These findings are currently being verified through full scale track testing to ensure that the sanding rates do not compromise train detection, and to determine improvements in braking using different distributed sander configurations in simulated low adhesion conditions (T1107). The findings are expected to become available in early 2018.

Trains with fewer than eight axles

The RGS for multiple unit sanders contains specific requirements to guard against laying excessive sand, including a maximum sand laying rate, and requirements for a minimum of eight axles on a unit with sanders to disperse the sand. This meant that certain vehicle types, such as the single car Class 153 multiple units and four-axle Class 14X 'Pacer' units, were outside of the criteria. The requirement for six following axles was due largely to the data available to the industry at the time, which had been gained from empirical tests using the original automatic sander type (appendix A2.3.3.2) on two-car, eight-axled multiple units.

Vossloh Kieppe UK Limited, in conjunction with Bombardier Signals, train operators and ROSCOs, developed a safety case for an accepted solution for Class 14X and 153 units in response to concerns from the operators of these units, particularly following incidents in 2009 and 2010. The sander system for the four-axle units differs from the two-car plus unit system in that it has the sand delivery ahead of the leading axle, all other compliant systems have the sand delivered ahead of the third axle. The equipment making up the system is the same as for other fleets fitted with the Vossloh Kieppe supplied sanding systems. Sanding is available in brake steps two and three, and automatically when Emergency Braking is selected.

The RGS requirement was largely driven by needing the leading bogie to generate WSP activity and trigger the sander for the rest of the train. The front axle was chosen for the four-axle units as one axle represents 25% of the braking of the unit and, as there is no WSP system fitted, there was no need to allow the front axle to slide. Note that sander systems fitted to Class 14X and 15X (except Class 158 and 159) are not standard; because WSP is not fitted sanding is not automatic and is instead manually controlled by the driver using a pushbutton, i.e. the driver is used as the low adhesion detection system and he / she is then responsible for pressing the cab button to lay sand. This simple system has worked well on the Class 150s for many years and was the obvious choice for the four-axle units. Additionally, drivers of Class 14X and 153 units usually also drive sander fitted Class 150 and 156 units as well, so a common arrangement is good for driver training and competence purposes.

To allow this system to be deemed safe by RSSB in terms of the effect on track circuits, a preliminary approach was made to the relevant safety approval panels. They indicated they would support the fitment but some on-track tests to prove track circuit performance was no worse than the RGS compliant system were needed. Bombardier Signals engineers determined that a track circuit was unnecessary for the tests as all track circuits must meet a common Network Rail specification. That states that all track circuits irrespective of type must operate with a ½ ohm resistance at the far end of the track circuit length. A test resistor on a pair of tongs was used to check track circuit operation the

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½ ohm resistor representing the worst case train resistance (most trains on dry rails with no contamination can meet the ½ ohm limit easily).

The tests, at Tuxford station, showed that with 2kg/min laid at the front axle the minimum speed below which the resistance was greater than ½ ohm was 10mph. This is the same speed and sand delivery rate specified in the RGS.

Sanding on axle one and sanding on vehicles of under eight axles is now permitted as long as track circuit compatibility and train detection can be assured. Issue one of GM/RT2461 required an application to RSSB for a standards deviation to do this, whereas the latest issue does not. GM/RT2461 issue two requires compatibility assurance to be demonstrated and accepted by all relevant parties without the need for a standards deviation.

Sanding in brake steps 1 and 2

Deviations to RGS GM/RT2461 exist for some disc braked fleets to allow sanding in brake step one and step two in addition to step three (full service) and emergency, to enable sanding when utilising a more conservative brake application on approach to an affected area.

For tread braked units with manually activated sanders, sanding has been limited to brake step two and above, where it is considered more likely that wheel slide will occur, and that sand may not be as effective in improving adhesion when applied to non-rotating wheels. Drivers need to manage the brake to lay sand in front of rotating wheels but the minimum application (step two) is likely to lead to locked wheels. Operators of tread braked fleets have proposed that the system would be more effective if it allowed sand to be discharged early, either before braking commenced, or during step one braking. Some operators have now already moved to enabling pushbutton sanding on Class 14X and 15X units in step one and even in coasting to improve the grip during and before low rate brake applications.

Sand box capacity

The capacity of sand boxes will of course limit the availability of the sander system; the Achilles heel is the need to keep sand boxes topped up under all operating conditions. A sand box which may need only to be topped up at scheduled exam intervals (four to six weeks) in spring and summer may need topping up every two to three nights in autumn. This places management, staffing and berthing challenges on train operators. An incident at Stonegate in Kent in autumn 2011 (RAIB report) highlighted the importance of robust sand usage monitoring and replenishment regimes. **Sanders should be treated as 'safety critical' and appropriate instructions put in place for managing trains**

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with empty sand boxes. The inclusion of sand box level detection in the design, flow rate monitoring or usage calculations based on, for example, WSP activity and sanding rate, should be considered to provide targets for monitoring and inspection. Suppliers can now provide systems with digital or analogue sand level indicators and some systems can calculate the sand used in order to predict the sand level.

WSP system failure

It is possible that a system failure, particularly within the WSP, may inhibit sander operation. GM/RT2461 permits the sander to be activated at 7.5g/m sand laying rate when Emergency Braking is selected to ensure that a dynamic means of adhesion improvement is available to the driver in emergencies. Many installations invoke sanding whenever the brake controller is placed to the Emergency position, regardless of whether WSP activity is present or not.

Driver reliance on sanders

Early concerns that drivers may come to rely on the sanders for braking in deference to defensive driving techniques have not been borne out in practice.

A2.3.3.4 Sanding in traction

Due to concern about the long-term infrastructure effect of sanding at very low speeds over points and crossings, traction sanding is currently specified to be under driver control from a cab-mounted button, and **drivers must be instructed not to apply sand when the train is passing over points and crossings**. On most modern units, drivers can only apply sand if there is wheel spin occurring, which prevents sanding 'just in case spin occurs'.

To improve traction on multiple units where the powered vehicle(s) are not the leading sander-fitted vehicles, it is usual to install an additional sanding unit for traction only, which will lay sand ahead of the motored axles which otherwise would experience a much reduced benefit for the sander fitted on the leading non-powered vehicle.

A2.3.3.5 Managing sand

Handling sand and storage

The quality of sand used, and the correct handling and storage are essential to maintain reliable sander operation. Constant handling of sand can cause the larger grains to break down into a fine powder, so handling should be kept to a minimum. Sealed containers should be used to transport the sand in order to prevent moisture from being absorbed. When compressed air is used to force the sand through pipes for short distances (e.g. if filling hoppers using compressed air) it should be at low pressures. Sand should be stored in dry conditions as any dampness will lead to sand clogging in the valve.

Note that the grade of sand used in multiple unit sander systems is defined in GM/RT2461. It is not the same grade of sand as that typically used for locomotive traction adhesion mitigation and the two grades should not be mixed up.

Sand Hopper Filling

The safety and efficiency of sand hopper filling is an issue. Clearly the primary aim is to ensure that the sand levels in hoppers are checked and topped up frequently. The method of filling should be as simple as possible to assist busy depot staff and it should be achieved in a safe manner.

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The first thing that operators and maintainers should be aware of is that dust inhaled during the handling of sand is a safety risk. **All operators are obliged under Health and Safety Regulations to have a COSHH statement on this issue and to have suitable practices in place to minimise the health risk.** COSHH information should be available from the supplier.

The sand used by the automatic sander fitted stock is relatively coarse and may seem to present little health risk. However, the handling of sand during transportation and filling operations causes some breakdown of the particles so that a hazardous air-borne dust is produced. Three methods of sand hopper filling are used:

The **manual** method is the most widely adopted. Sand is normally supplied in 25kg bags and must be poured into the hopper, which means that the operator is very close to any dust that is generated. **A mask to protect nose and mouth, together with eye protection, is recommended**. It is often difficult to ensure that the sand hopper is full, and some means of pushing the sand to the back of the hopper is often necessary. **A hopper design with a filling aperture that is as large as practical will make the process easier.**

A **pressurised** sand hopper filling system works in much the same way that the vehicle sanders operate. Sand is moved under air pressure from either a portable hopper at the vehicle side or from a storage tank into the vehicle hopper. The process causes a blow-back from the hopper, which will carry significant amounts of dust so that some form of filtration or personnel protection is necessary. The filling process is less labour intensive than manual methods, is more efficient in ensuring that the train hopper is filled completely and limits the amount of heavy lifting required.

Companies such as Schenck Process market bespoke sand filling solutions. A sand filling system can consist of a large static hopper feeding, via a network of pipes (filling stations) around a depot / sidings, and petrol pump type nozzles. Sand is transferred under pressure with dust emission eliminated by a simple exhaust system. The sand flow is automatically stopped when the sand box is full.

An alternative to the pressurised system described above is the **vacuum** system from AEA Technology Rail (which became DeltaRail Group). The train hopper is sealed, and a negative pressure is created inside so that sand is sucked in. Any air-borne dust is filtered during the filling process. The equipment, including a sand hopper, is contained on a wheeled trolley that is positioned at the vehicle side. An empty vehicle hopper can be filled with over 35kg of sand in around five minutes.

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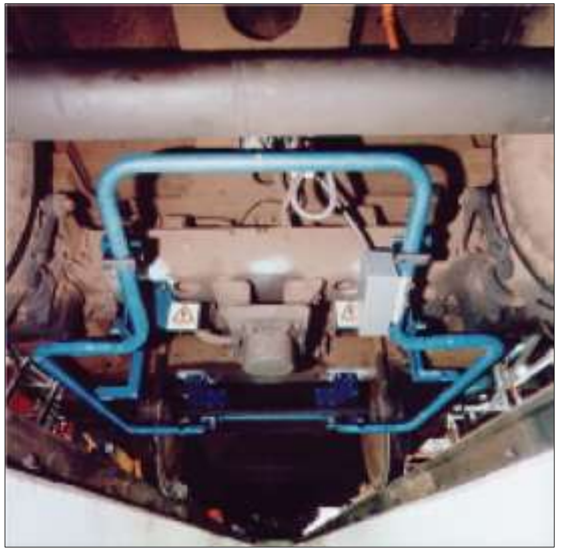
A2.3.4 Auxiliary tread brakes

Auxiliary Tread Brakes (ATB), sometimes known as scrubber blocks, have been fitted to certain disc braked multiple units to assist in cleaning the wheel treads. They are applied each time the driver makes a brake application and rub against the wheel tread thus cleaning it. The disc brakes remain responsible for the service braking.

Limitations

- ATBs only operate when a brake application is made therefore a train accelerating or coasting over a contaminated site will see little benefit to improved track circuit operation;
- ATBs generally only give a benefit for a short period each year (maximum of 16 weeks);
- ATBs offer little benefit to improving braking under low adhesion conditions;
- ATBs increase the noise and vibration inside the vehicle thus worsening the passenger environment.

A2.3.5 Track circuit actuators / assisters



The objective of the track circuit actuator (aka assister and TCA) is to assist the operation of track circuits by breaking down the electrical insulation properties of certain contaminants on the railhead. On lines with a low train density (that is, infrequently used lines or those with short, relatively lightweight trains), disc braked diesel multiple units with modern bogies can roll contamination (oil, dust, pollution from rain etc.) into the rust on the railhead. In dry weather this creates a layer which, because of its composition, creates an electrical resistance between wheel and rail. However, if a high enough voltage is created across the insulating layer, its resistance falls and the track circuit can operate normally. TCAs can be fitted to provide this high voltage. Leaf film, on the other hand, is an insulator that will not be broken down at practical TCA voltage levels. Only one initiative, the Track Circuit Actuator Interference Detector has been specifically targeted at this problem (section 6.3.4).

Railway Group Standard GM/RT2477 “Track Circuit Assister Configuration for Rail Vehicles” sets out mandatory requirements for the provision and operation of TCAs.

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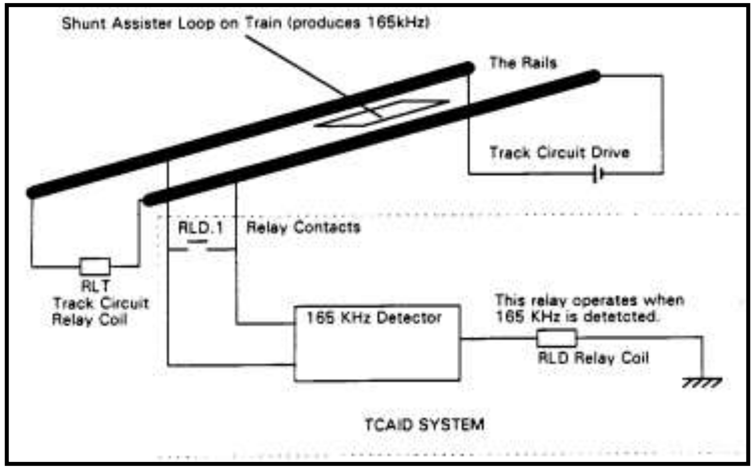
Operation



The equipment is relatively simple: a metal loop mounted beneath the train acts as the primary winding of a transformer; the circuit formed by the wheelsets of one bogie and the rails acts as the secondary winding. When the loop is supplied with an alternating current at high frequency (165kHz), it induces a voltage in the secondary circuit. As the secondary circuit includes the contact point between the wheels and rails, the voltage across the insulating layer is raised above the critical level, so that track circuits can be completed in the normal manner. In effect, the TCA clears the path so that the track circuit can operate properly.

As TCAs are relied upon to assist the actuation of track circuits, indication of the status of the TCAs on each train should be provided to the driver. Then, in the event of failure, appropriate operating instructions can be observed to preserve safety. These operating instructions may require the train to be taken out of service, however this is now dependent on the fleet. RSSB has developed a 'Risk Advisor Tool' for assessing whether vehicles currently fitted with track circuit assisters (TCA) can be allowed to operate with a failed TCA (T579 and T1005). A new Rail Industry Standard is being currently being written to support its use.

Limitations

- The TCA was designed to deal with railhead contaminants such as rust, without interfering with the normal operation of track circuits or affecting staff safety. The TCAs have little or no effect on severe leaf contamination in dry weather because the voltage required for this (upwards of 400V) is greater than that which can be produced by the TCA for safety reasons.
- **TCAs can only be used with certain types of track circuit. It is very important that the compatibility between TCA and track circuit type is assessed prior to using TCA fitted vehicles over routes not previously traversed with such equipment.**

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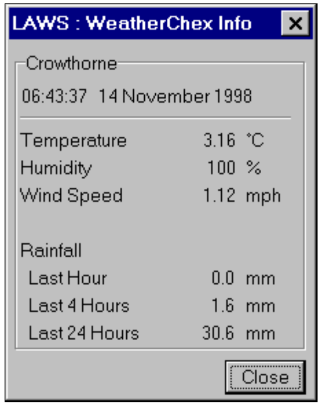
A2.4 Information solutions

This section describes three solutions using trainborne systems to provide information that can help the industry mitigate the effects of low adhesion. They are not solutions in their own right, but means to provide better solutions to the industry.

A2.4.1 Low adhesion warning system

DeltaRail Group developed a system known as the Low Adhesion Warning System (LAWS™). LAWS™ works by monitoring a train's WSP system for wheel slip in braking or wheelspin in traction as an indication of the presence of low adhesion conditions. Although no longer used in GB following a number of trials, LAWS™ is used in the Netherlands.

By combining this with accurate train location data, a map of low adhesion sites can be generated, and appropriate advice can be given to train drivers and remedial measures undertaken. Upon detection of wheel slip or wheelspin, a message is transmitted automatically to an office based PC by means of digital cellular mobile phone. This message, transmitted in real-time, uses the GSM Short Message Service (SMS) and contains data on the train's position and speed, the time of the event, the duration of the event and the brake step or power notch applied. The information from each vehicle is received by the Low Adhesion Mapping computer which allows the operator to be alerted to the presence of low adhesion at that location. The operator can:



- receive warnings in real-time about low adhesion events;
- view the development of low adhesion conditions over time;
- track the location of vehicles as they move about the network;
- identify and view event severity via a colour coded map;
- search the database for particular events or sites.

The record of low adhesion events is based on defined sections of operating routes. As fitted vehicles report low adhesion events on particular sections of map, low adhesion sites are automatically built up, and the severity of sites can be assessed by the number and type of incidents that occur.

If there are weather stations in use as well, then the operator can view details of temperature, rainfall, humidity, wind speed and dew point at various locations also to enable decisions to be taken about the likelihood of low adhesion conditions occurring.

Depending on the proportion of vehicles equipped with the system, this information can then be used in a number of ways:

- an up-to-date list of problematic sites can be posted at the driver's signing on location;
- the information can be used to target day-to-day remedial measures such as railhead treatment;
- by logging the wheel slip and wheelspin events, a 'historical picture' of adhesion conditions over an entire season can be generated and this can form a basis upon which to improve the effectiveness of longer-term remedial measures such as lineside vegetation management;
- a warning message can be broadcast to trains in the vicinity of and / or approaching the low adhesion site, using for example train radio, e.g. GSM-R. In the Netherlands, a message is transmitted direct to staff on a mobile phone.

Most of the trainborne hardware is based upon well proven on-train monitoring equipment developed for various other applications such as passenger load weighing and condition monitoring. It comprises a sealed box containing the computer, satellite navigator, cellular telephone and modem. Two aerials are provided (one for each of the navigation and communications systems) mounted on the longitudinal centreline of the roof. Additional cable connections are required for train speed, and for traction and braking control signals.

The LAWS™ computer monitors WSP activity during power and braking. Any WSP activity is recorded and classified against brake step or power notch in order to identify both wheel slide and wheelspin events. The time span of the WSP activity is also recorded along with train speed, location and direction. The determination of geographical

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position is achieved using a combination of satellite navigation with distance derived from train speed and time. The on-board satellite navigator is used to determine which section the train is occupying and the tachometer pinpoints position along the track. The message transmission, display and logging is fully automated.

Ideally, every unit in a fleet would be equipped with LAWS™. This would enable low adhesion sites to be identified as soon as they start to cause problems to train services. A comprehensive implementation would also enable the system to provide automated warnings to drivers in the vicinity of low adhesion sites.

A2.4.2 Remote Condition Monitoring systems

Many rail vehicles are fitted with Remote Condition Monitoring (RCM) either as part of the original design by the vehicle manufacturer, or as a result of later installation. As well as supporting later investigations, outputs from these systems can be used to provide real time advice of low adhesion related incidents and help inform a response 'on the ground', e.g. hand sanding (appendix A2.2.8). Even if not part of the original RCM design, it is normally straightforward to retrospectively develop rules for alarms and alerts.

Greater Anglia has retrofitted WSP to their Class 156 fleet which also includes recording of WSP activity train location and data export. An example 'heat map' is shown adjacent.

Southern's Class 377 fleet also records and exports WSP activity events in a similar fashion.

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A2.4.3 On-train data recorders

In their report into the buffer stop collision at Chester station in November 2013, RAIB noted the value of analysing On-Train Data Recorder (OTDR) data for all trains operated over a route to identify where sustained WSP activity is experienced. Some train operators use this information to warn drivers of areas at risk from low adhesion, and to inform the infrastructure manager of areas where railhead treatment is required.

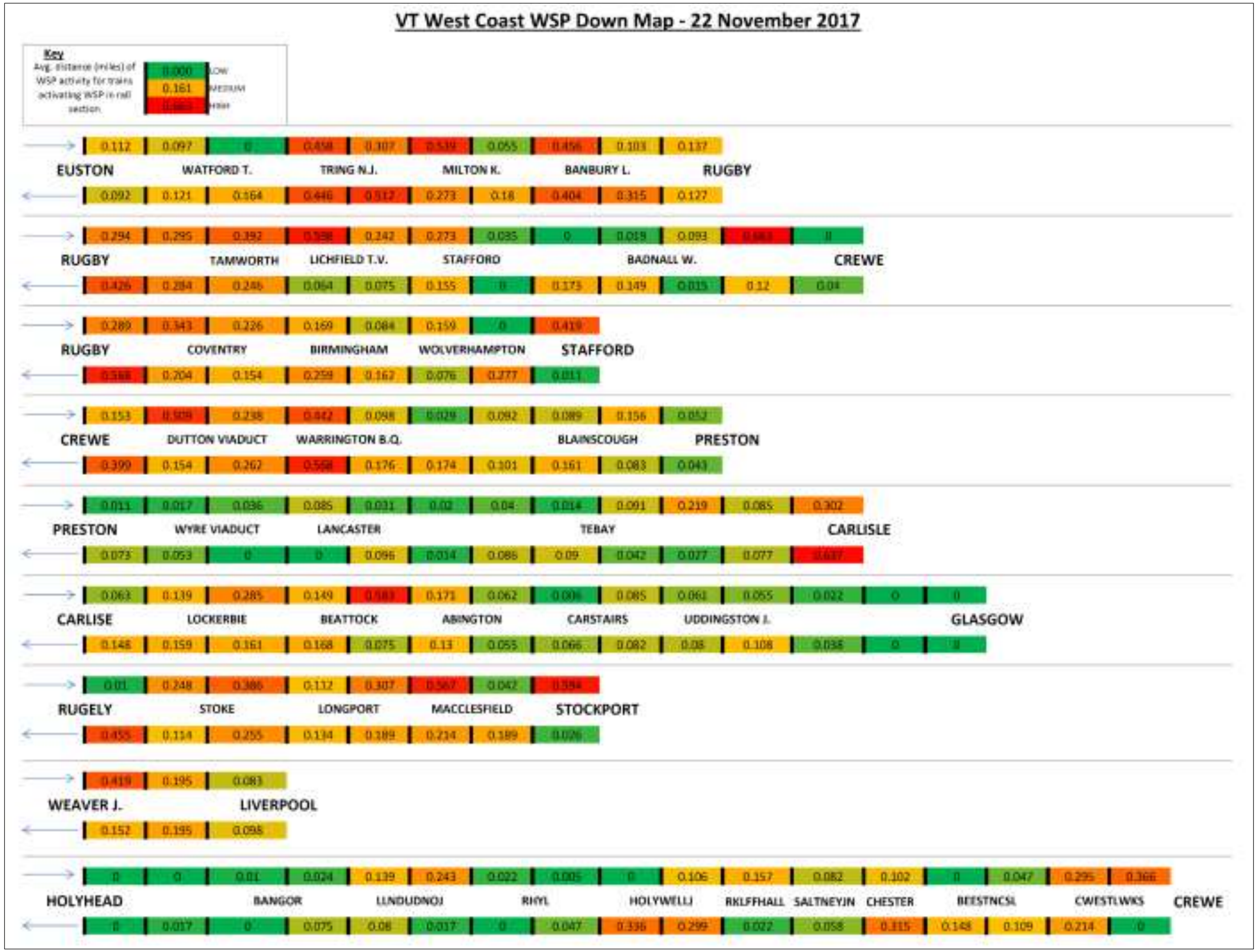
Every train that operates on the mainline now carries an OTDR, a 'black box' recorder. OTDRs normally record data that can be related to the level of adhesion along a section or route, such as WSP activity, brake demand levels and achieved deceleration. Coupled with location information, OTDRs can then provide detailed data on adhesion levels.

A good example of the use of OTDR data comes from Virgin Trains who have been extracting WSP data from their Pendolino (Class 390) and SuperVoyager (Class 221) trains on the West Coast Main Line since 2004. Data has been downloaded every weekday for routine analysis during the leaf fall season. The OTDR data is used to investigate driver and train performance / behaviour, looking for consistency and the infrastructure state. In addition, the data is used for incident investigations (such as at Chester station) and low adhesion analysis. For example:

- length of WSP activity in distance and time;
- sand usage based on WSP time duration associated with low / medium / high risk level;
- driver behaviour in low adhesion conditions, i.e. adherence to driving policy;
- comparison against adhesion risk reports provided by Network Rail.

Downloads are undertaken via Wi-Fi, at the end of a journey or at any other time when the train is stationary (to avoid file corruption). The train operator is able to access the data almost in real-time following an event they wish to look at. Files are exported to a bespoke OTDR Auto-Analysis Tool developed by Virgin Trains. The analysis can take from a few seconds to many hours depending on the complexity of the analysis required. There is a significant advantage in operating with TASS balises which provide an accurate position reference source. The alternative is to manually match unit numbers and times from the OTDR data with times from Trust and unit allocations from Genius to obtain approximate locations; a time consuming exercise.

A typical output is shown below.


VT West Coast WSP Down Map - 22 November 2017
Key
Avg. distance (miles) of WSP activity for trains activating WSP in rail section
LOW
MEDIUM
HIGH
EUSTON
WATFORD T.
TRING N.J.
MILTON K.
BANBURY L.
RUGBY
RUGBY
TAMWORTH
LICHFIELD T.V.
STAFFORD
BADNALL W.
CREWE
RUGBY
COVENTRY
BIRMINGHAM
WOLVERHAMPTON
STAFFORD
CREWE
DUTTON VIADUCT
WARRINGTON B.Q.
BLAINSCOUGH
PRESTON
PRESTON
WYRE VIADUCT
LANCASTER
TEBAY
CARLISLE
CARLISLE
LOCKERBIE
BEATTOCK
ABINGTON
CARSTAIRS
UDDINGSTON J.
GLASGOW
RUGELY
STOKE
LONGPORT
MACCLESFIELD
STOCKPORT
WEAVER J.
LIVERPOOL
HOLYHEAD
BANGOR
LLNDUDNOJ
RHYL
HOLYWELLJ
CHESTER
CREWE

Reports are sent out each day, using OTDR information from the previous day, as well as from trains terminating earlier that same day, to help highlight potentially poor adhesion areas to drivers. The information is also sent to Network Rail.

South West Trains (now South Western Railway) have also introduced a system based on data from trains. Data is downloaded from Desiro trains and fed to a 'Google Fusion' table to populate an interactive map. This can then be used to identify where resources need to be deployed.

OTDR data has also been used for:

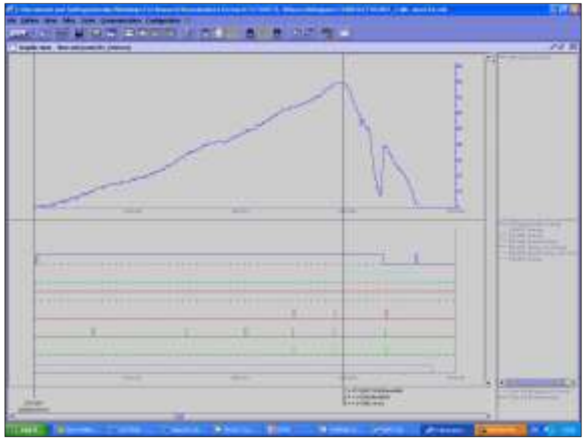
- collating locations and details of WSP events over a specified distance threshold and sharing with Network Rail to inform railhead treatment;
- analysing data from problem sites to establish likely conditions on the line before and after the RHTT;
- using the data to validate and improve route forecasts in the Met Office low adhesion model.

Guidelines for analysing data

It is important that people undertaking analysis of data recorder outputs are themselves competent in both the analysis techniques and how the train should be driven on the route concerned. This requires a thorough knowledge of the optimum speed profile and braking points for the route and fleets concerned. To do this, a 'perfect' run can be made across the route to establish a data recorder output representing good driving technique over the route. This makes identifying train driving techniques simpler as the two outputs can be directly overlaid to identify any differences.

It is also important that the analyst has a good understanding of how the data is sourced and any impacts on the data from systems such as WSP. The following are common 'traps' that the unwary can fall into:

- The speed output shown on the OTDR data may be affected by the action of the WSP controlling the wheelsets in 'slip' (the wheels are turning slower than the train's forward speed). This can be seen in the adjacent output. The troughs in the speed trace represent the wheelset speed (i.e. of the wheelset driving the OTDR speed input) being controlled at slip speed and the peaks represent the real speed when the WSP allows the wheelset to regain true vehicle speed. In examples such as this it should be assumed that the true vehicle speed follows the peaks and a curve can be drawn across these to provide the real speed reference.

  However, Virgin Trains have overcome this problem by isolating the brakes on the leading axle (where the speed is recorded) so that it is free to roll and hence record the true forward speed of the train. This is best practice for operators with older stock where braking capability allows – newer stock may have an independent way of recording speed, such as a radar.
- The speed output may be affected by the wheelsets going into a 'deep slide' (near lock-up), or full lock-up, as shown in the output.

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- The speedometer input to the OTDR may be derived as an output from the cab speedometer, and its accuracy may be affected by: the accuracy of the wheel sizes recorded in the brake control unit and / or the brake control unit's ability to determine or calculate true train speed in conditions of wheelspin or wheel slide.

A3 Vegetation management guidelines

Vegetation management is an environmentally-sensitive issue and should be undertaken in accordance with laid down procedures. The policy adopted by the Network Rail is:

'to maintain its linesides in a professional and sympathetic manner and to work as far as practicable in harmony with the natural processes in the environment'

Leaf fall remedial action may require drastic initial measures, in particular the long-term remedy of reducing the number of leaves at source means coppicing (removing to a stump from which new shoots will sprout) or even felling large mature trees.

This can be done sensitively as part of a 'sustainable long-term lineside management package'. The aim should be to reduce areas of Vegetation Severity Index Category 4 and 5, which have been confirmed as potential leaf fall problem sites, to Category 2 or 3, and to ensure that Category 2 or 3 sites do not become Category 4 or 5 sites in the future. A 'scorched earth' policy aimed at creating a uniform Category 1 trackside is impracticable, costly and environmentally unacceptable.

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The following photographs taken at East Farleigh show a Category 3/4 site cutting before and after remedial actions which reduced it to Category 1.


The aim should be to:

- clear vegetation from a five metre band adjoining the rail;
- fell only those species of trees on railway land identified as causing leaf fall problems (appendix A4).

Experience shows that felling large trees, whilst expensive at £20,000 to £50,000 per mile, can eliminate future leaf fall problems and is a long-term solution. Provided the stumps are killed and other smaller trees controlled, then the solution is permanent. However, care must be taken to ensure that killing trees does not lead to unstable embankments.

The 'Troublesome Tree Chart' (appendix A4) provides pictures of the leaves, blossom and fruits of the most problematical trees and should help in identifying the types of trees causing most problems during the leaf fall season.

Lineside clearance

Clearing of vegetation for up to five metres from the rail can be assisted by track-mounted flailing machines although this method is not sustainable long-term. For the initial clearance after years of neglect, manual assistance may be required to hand cut trees too thick for flailing (70mm diameter). More modern equipment such as the Bracke harvesting head can be used to fell small to medium trees up to six metres from the rails.

All debris should be removed (chipping may provide a practical way of disposal) and stumps should be treated with a herbicide to avoid encouraging new growth.

Once the trackside strip has been cleared, it will revert to a meadow type environment and can be maintained by further flailing.

Tree felling

Felling of large trees must be handled with sensitivity. Trees identified as a potential risk must be clearly marked for felling. Once again, all timber should be removed from site and cuttings chipped. Stumps should be killed.

Mature timber may have a commercial value. Before clearance starts, markets should be sought for timber to be cleared. The Forestry Commission should be able to provide suitable advice.

Replanting

Inevitably, there will be areas where all the trees are of the same species and must be removed. In this case, provision should be made for planting replacement trees which do not produce leaf fall problems. Appendix A5 of this manual provides guidance on suitable tree species to plant.

When an area has been cleared, particularly where leaves from private land may continue to be a problem, consideration should be given to planting small shrubs in diagonal strips along the edge of the verge. This arrangement traps fallen leaves and also breaks up the slipstream from passing trains, reducing the risk of leaves being picked up and deposited on the track bed.

Private land

As part of the categorisation of the track, locations will be found where trees causing leaf fall problems are on private land beside the line. These should be listed separately so that the land owners can be approached to see whether they can assist in removing the problem.

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Summary

Vegetation management is the single most effective remedy for low adhesion because it eliminates or reduces the leaf fall problems at source. However, it is not a once-and-for-all operation and the benefits are not limited to the autumn. It must be routine.

Routine vegetation management is good safety practice because:

- it improves visibility of signals and lineside signs;
- it improves visibility for trackside staff and contractors, and ensures adequate warning for lookouts;
- it improves visibility for drivers and road users at the approaches to level crossings;
- the cleared walkways maintain a safe area for staff and contractors walking the track;
- access to signal cabling is kept clear.

A4 Troublesome tree chart

The following photographs identify the most troublesome trees as far as low adhesion is concerned.

Sycamore

Horse Chestnut

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Sweet Chestnut

Ash

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Poplar

Lime

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A5 Tree matrix

Planting locally native species

The following tables list a number of plant species that are suitable for planting at >5m and >10m from the outside rail. All of these species are suitable for planting along the lineside and are native to Great Britain. It is though possible to choose, from the various species available, those species that are native to the area you are planting. This adds further value to the planting, directly contributing to local native species conservation in Britain.

Native plants in Britain are those that were already present before the formation of the English Channel. 'Introduced' species or 'aliens' originate from places other than Britain and have usually been transported here by humans. A species can be native to Britain, but not native to an area. Locally native plants could be described as the backbone of local ecology. Insects, birds and other animals cannot survive without the food and shelter they provide. In contrast, introduced plants usually offer little to our native wildlife. This is strikingly illustrated by examining native trees, such as oak or hawthorn, and aliens like horse chestnut and 'London plane'. Few insects or other invertebrates will be found on the foreign species and its leaves will be virtually untouched, whereas by comparison a native tree harbours innumerable invertebrates.

Possible species for planting >5m from the outside rail

Scientific name	Common name	Vegetation type				Safety considerations					Conservation factor			Visual impact			Security		Comments
		Ground cover	Shrub	Hedge	Small tree (<10m)	Stable root systems	Slow growing	Evergreen	Light leaf-fall	Non-brittle branches	High bird value	High insect value	High mammal value	Attractive foliage	Attractive blossom	Attractive fruit	Dense	Thorny	
Acer campestre	Field maple				x	x				x	x	x	x	x					Native replacement for sycamore, slower growing and smaller
Betula pubescens	Downy birch																		
Corylus avellana	Hazel		x	x						x	x	x	x			x			
Crataegus laevigata	Midland thorn			x	x				x		x	x	x		x	x	x	x	
Crataegus monogyna	Common hawthorn		x	x	x				x	x	x	x	x		x	x	x	x	Ideal barrier hedge
Cytisus scoparius	Broom	x	x			x		x	x	x		x			x				
Erica/Calluna	Heather	x	x			x	x	x	x	x		x			x				Good, easy maintenance ground cover
Frangula alnus	Alder buckthorn		x	x			x		x	x		x	x			x	x	x	
Hippophaë rhamnoides	Sea buckthorn		x	x		x			x	x	x			x				x	Resistant to salt
Ilex aquifolium	Holly			x	x		x	x	x	x	x		x			x	x	x	Ideal barrier hedge
Juniperus communis	Juniper		x			x	x	x	x	x	x					x			
Ligustrum vulgare	Wild privet		x			x	x	x	x	x		x					x		Hedge
Malus sylvestris	Crab Apple				x				x	x	x	x	x		x	x			

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Possible species for planting >5m from the outside rail (continued)

Scientific name	Common name	Vegetation type				Safety considerations					Conservation factor			Visual impact			Security		Comments
		Ground cover	Shrub	Hedge	Small tree (<10m)	Stable root systems	Slow growing	Evergreen	Light leaf-fall	Non-brittle branches	High bird value	High insect value	High mammal value	Attractive foliage	Attractive blossom	Attractive fruit	Dense	Thorny	
Prunus spinosa	Blackthorn		x	x		x			x	x	x	x	x		x	x	x	x	Ideal barrier hedge
Pyrus communis	Wild pear				x		x			x		x			x	x			
Rhamnus catharticus	Buckthorn		x	x			x		x	x		x					x	x	Ideal barrier hedge
Rosa arvensis	Field rose	x		x		x			x	x	x	x	x		x	x		x	Thorns
Rosa canina	Dog rose	x		x		x			x	x	x	x	x		x	x		x	Thorns
Rubus fruticosa	Bramble	x							x	x	x	x	x		x	x		x	Thorns
Sambucus nigra	Elder		x	x						x	x	x	x		x	x	x		Vigorous growth
Sorbus aria	Whitebeam				x	x				x	x		x	x	x	x			
Sorbus aucuparia	Rowan				x		x		x	x	x		x	x	x	x			
Sorbus torminalis	Wild service tree				x		x			x	x	x	x	x	x	x			
Taxus baccata	Yew				x	x	x	x	x	x	x	x	x			x			
Ulex europea	Gorse	x	x					x	x	x	x	x	x		x		x	x	Thorns
Viburnum lantana	Wayfaring tree		x	x		x				x	x		x		x	x			
Viburnum opulus	Guelder Rose		x	x		x			x	x	x	x	x	x	x	x			

Possible species for planting >10m from the outside rail

Scientific name	Common name	Vegetation type					Safety considerations					Conservation factor			Visual impact			Comments
		Ground cover	Shrub	Hedge	Small tree (<10m)	Large tree (>10m)	Stable root systems	Slow growing	Evergreen	Light leaf-fall	Non-brittle branches	High bird value	High insect value	High mammal value	Attractive foliage	Attractive blossom	Attractive fruit	
Alnus glutinosa	Alder				x						x	x	x					High conservation value, nitrogen fixing, good for reclamation work
Betula pendula	Silver birch				x						x	x	x		x			Can be unstable when older, prolific regeneration
Carpinus betulus	Hornbeam				x		x	x			x							
Fagus sylvatica	Beech					x								x				Shallow rooted and susceptible to storm damage, potential hedging species
Juglans regia	Walnut					x		x									x	
Pinus sylvestris	Scots pine					x			x	x								
Populus tremula	Aspen				x		x				x		x					
Prunus avium	Wild cherry				x						x	x	x		x	x	x	
Prunus padus	Bird cherry				x						x	x	x		x	x	x	
Quercus petraea	Sessile oak					x	x	x				x	x	x			x	
Quercus robur	Common oak					x	x	x				x	x	x			x	
Ulmus carpinifolia	Smooth-leaved elm																	
Ulmus glabra	Wych elm			x	x						x		x					
Ulmus minor	English elm				x	(x)												Restrict height to reduce risk of Dutch elm disease

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Species that should NOT be planted

Scientific name	Common name	Vegetation type					Safety considerations					Conservation factor			Visual impact			Comments
		Ground cover	Shrub	Hedge	Small tree (<10m)	Large tree (>10m)	Stable root systems	Slow growing	Evergreen	Light leaf-fall	Non-brittle branches	High bird value	High insect value	High mammal value	Attractive foliage	Attractive blossom	Attractive fruit	
Acer pseudoplatanus	Sycamore					x												Leaf-fall problem species, invasive, vigorous growth, prolific regeneration
Aesculus hippocastanum	Horse chestnut					x					x		x	x		x	x	Leaf-fall problem species, potential trespass issues to obtain conkers
Castanea sativa	Sweet chestnut					x	x				x			x			x	Leaf-fall problem species, profitable timber crop - especially coppice
Fraxinus excelsior	Ash					x												Leaf-fall problem species, vigorous growth, prolific regeneration
Populus nigra var. *betulifolia*	Black poplar					x												Leaf-fall problem species, can be unstable
Populus nigra var. *italica*	Lombardy poplar					x												Leaf-fall problem species, can be unstable
Tilia cordata	Small-leaved lime					x							x					Leaf-fall problem species
Tilia platyphyllos	Large-leaved lime					x							x					Leaf-fall problem species
Tilia x europea	Common lime					x							x					Leaf-fall problem species

A6 Compendium of ideas

	Method	Observations	Results
1	Tree clearance and root killing	Labour intensive. Large reduction in volume of leaves reaching ballast area. Bank stability could be compromised. Not environmentally sensitive.	Similar to the traditional maintenance methods from the days of steam trains which achieved good results. Removes source of leaf film contamination.
2	Tree management – selective clearance and planting	Requires the services of skilled arboriculturalists. Some expense in selective planting. Could take some years to reach maturity. Environmentally more acceptable than tree clearance.	Generally, a sound long-term method. Environmentally friendly and publicly acceptable.
3	Chemical treatment	Little information on suitable chemicals for defoliating trees. May be possible to develop substances but environmental problems of pollution and health hazards possible. 'd-limonene' successfully used to break down leaf film layer on railhead.	Tests with hydrogen peroxide had no effect on defoliating trees. Orange cleanse and Natrusolve (d-limonene based) tested and eases breakup of leaf film. Now in regular use.
4	Inject trees with dwarfing agents (e.g. moleic hydrazide)	Would retard growth of saplings and hence future volume of leaves.	Trial by ICI PLC. Results not encouraging.

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	Method	Observations	Results
		Would not reduce leaves from established growth.	
5	Spray with leaf bud suppressant (Krenite)	Repetitive spraying would kill trees, necessitating removal. Would reduce volume of leaves.	Idea rejected because impractical and problems with accurate spraying.
6	Micro-biological techniques	Very slow acting	Not tried because of possible bad effect on adhesion.
7	Adhesive spray on fallen leaves	Could be used in troublesome locations. Would need to be repeated frequently and be biodegradable.	A rather optimistic idea – not very practical.
8	Apply heat just prior to leaf fall	Could alter structure of leaf and its aerodynamic properties. Could also affect next year's growth. Requires high energy consumption.	Idea rejected because impractical.
9	Leaf fences / hedges	Many trees too high and trajectory, when falling, carries over the fence. Maximum practical height of fence about 3.5 metres. Fences expensive to erect and require maintenance.	Used successfully at particular locations suited to the method e.g. Huntly (Scotland), Hightown (Merseyside) and at Witley Bank (Wessex Route).
10	Leaf traps	Can be constructed so that eddies deposit leaves away from ballast. Shortage of land a problem.	Method used successfully to prevent snowdrifts on roadways and railways. Not pursued.

	Method	Observations	Results
11	Leafguard	Lightweight UPVC blades clipped into plastic rail clips to encourage favourable vortices to direct leaves away from the wheel / rail interface.	Trialled extensively with encouraging results in reducing leaf contamination. However, labour intensive to install and remove each autumn as prone to warping if left installed during summer months. Not pursued.
12	Train mounted leaf guards in front of wheel to prevent leaves being crushed	All wheels need to be fitted with a guard on both sides. Limited space around wheels, risk to vehicle derailment.	Reasonably effective method which is difficult to engineer and may restrict maintainability.
13	Air dam fitted to front of vehicle to influence airflow	Shape of air dam / obstacle deflector significantly affects amount of leaves trapped by wheelsets due to aerodynamic properties.	Effects tested by BR Research in early 1990. Demonstrated four-fold increase can be seen due to poorly shaped air dam.
14	Train-mounted aerodynamic deflectors fitted to underside of vehicle	Difficult to optimise. Needs to create clean air in front of wheels.	Initially rejected in favour of developing the wheel guard type deflector.
15	Bogie-mounted fairings to influence air flow	Developed and tested by LaserThor.	Claimed 80% reduction in leaves trapped by wheelsets. Not developed further.
16	Vacuum collection of leaves	At high speeds, collection is difficult. At walking pace, complete removal	Method is used by LUL (two miles per night) and in Network Rail

	Method	Observations	Results
		is possible, but storage capacity limits operations.	London North East Eastern (limited use).
17	Train mounted leaf vacuum (ET2)	Proposed development of road based ET2 litter vacuum and compaction system. Proposed system for mounting on MPV. Unknown how frequent vacuuming would be required. Speeds relatively low.	Tested on Old Dalby test track. Demonstrated capability to collect dry leaves in the four foot.
18	Leaf collection by special scoops fitted to service trains	May effect some reduction in leaves on the ballast.	A rather optimistic idea and not very practical. Not followed up.
19	Plasma torch treatment train	Would depend on the behaviour of heated debris. High energy cost.	Tried for two seasons in Kent, abandoned in favour of water cannon. Method only works well on oil.
20	Water jetting	Pump pressure needs to be very high (up to 1500 bar). Water capacity and treatment speed may limit operation although use up to 60mph proven. Degree of success depends on frequency of use.	Original tests on medium pressure showed small reduction in leaf debris with no long-term adhesion improvement. Later trials with high pressure indicated better results at reasonable operating speed – now adopted by Network Rail as part of basic treatment trains.

	Method	Observations	Results
21	Sodium bicarbonate blasting	Traditional blasting method for other industries. Can be finely controlled.	Trialled during 2000/01. Speed of application low. Not proceeded with.
22	Trackside water sprays	Simulates excellent cleaning effect of natural steady rain. Drainage could be a problem. Adhesion may not be adequate for heavy freight trains. Problems with freezing and vandalism. Water drop size critical.	Keeps rails clean, but wet, so adhesion rarely above 15%. However, softens leaf film for removal by trains very effectively.
23	Rails in water troughs to keep them wet	Sealing of trough difficult. Gradients a problem for water level. Corrosion of rails a problem. Water freezing likely.	Idea rejected.
24	Train mounted water sprays	Needs large volume of water and slow speed. Will probably reduce adhesion.	Not tried because of possible adverse effects on adhesion.
25	Train mounted laser railhead cleaning	High power laser used to clear railhead of contamination. Mounted on MPVs. Aim is for small package to mount on service vehicles.	Trialled by Railtrack and Network Rail between 2000 and 2004. Potential to maintain a clean 40mm wide strip demonstrated. Efficiency affected by metal particles (wear debris) present in contamination. Not pursued by Network Rail following extensive testing.

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	Method	Observations	Results
26	Steam cleaning treatment train	None.	Little reduction in quantity of debris.
27	Sandite train	Standard treatment including the use of stainless steel grit when track circuits are vulnerable. Needs repeating and limited to 40mph laying speed. Alternative product TractionGel 60 (TG60) allows for greater laying speeds.	Good results. Adhesion increased by 5% on damp leaf film with a typical maximum value of 10%. TG60 now basic Network Rail treatment at up to 60mph.
28	Rail grinding	Unpowered grinding tested by Arup and Network Rail in 2003 worked at speeds below 10mph to avoid stone contamination. AEA Technology review of autumn 2003 found no evidence that grinding during leaf fall, or beforehand, reduced delays. Nor did they find evidence to support benefits from rougher rails following grinding.	Use of large rail grinding trains would provide clean rails, however, they are expensive to buy / operate and are slow compared with water jetting. Their priority has to be to reduce damage from rolling contact fatigue. AWG agreed not to endorse the use of these trains for anything other than an ad-hoc, exceptional autumn rail cleaning role.
29	Rail scrubbing	'Swedish Scrubber' tested with some success. Hand held and OTM fitted scrubbers used. Treatment speed low but removes leaf film contamination.	Success is speed sensitive. Does not clear completely at 30 mph. Special vehicles are expensive to purchase and operate.

	Method	Observations	Results
30	Trainborne rail scrubber	Scrubbing blocks made of disc pad material limited wear life. Problems with blocks being damaged on points. Blocks manually raised and lower by driver but GPS control developed and trialled. Considered that whole fleet would need fitting to be effective replacement for other measures. Cannot be used in conjunction with Sanditing.	Trials conducted on Romford Upminster branch 1999. Some anecdotal success. Trial of GPS controlled raising and lowering of blocks on Merseyrail autumn 2001. Not pursued in deference to other solutions.
31	Portable rail scrubbers	Two products in use in Network Rail, battery and petrol driven.	Used with success in localised cleaning but difficult to get to site.
32	Magnetic Track Brakes (MTB)	Uptake of MTB could improve braking performance giving drivers more confidence during low adhesion conditions, in turn reducing SPADs and station overruns.	In 2016, RSSB considered the technical compatibility and economic potential (T1099). No significant incompatibilities were identified that could not be mitigated, where MTBs were used for emergency braking only. Routes would though need be checked for compatibility. Potentially economically viable on new rolling stock.

	Method	Observations	Results
33	Tyre cleaning with Auxiliary Tread Brakes	Keeps disc braked wheels as clean as tread braked wheels. Extra brake gear on bogie.	Little effect on adhesion but 50% improvement in track circuit operation problems. Use expanded in 2011/12 to problematic multiple units (Class 158).
34	Tyre scrubber blocks	As tread brakes but more abrasive.	Slight benefit in BR tests. Expensive additional equipment.
35	Tread conditioning blocks	Similar to scrubber blocks but lighter force and left continuously in contact with tread.	Ineffective in BR tests (Southern Region).
36	Trainborne sanders – traction and braking	Used on some tramways and foreign railways. Now in use in Britain in various guises.	Effective in raising adhesion, no significant risk to track circuit operation or wheel / rail damage.
37	Wheel Slide Protection	Makes best use of available adhesion. Optimisation on WSPER™ rig.	WSP can increase adhesion slightly by conditioning rail / wheel treads. Good, optimised systems effective at reducing braking distance and wheel damage.
38	Autumn train detection techniques	TCAIDs used to detect presence of TCA fitted vehicle. Treadles used to activate crossings. Axle counters and wheel detectors also in use.	Extensively tested and proven. Some types of track circuit / sleeper cannot be fitted with TCAID.

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39	Leaf fall prediction	Data supplied by weather forecasters, e.g. Met Office using ADAS leaf fall prediction tool, MeteoGroup etc.	Reasonably accurate but predictions cover large areas.
40	Portable tribometers	Used to measure the adhesion levels on rails. Requires at least two persons to transport equipment.	Tested by BR Research and Railtrack / Network Rail. Not accurate for absolute measurements but can be used as guidance and identifying trends.
41	Low adhesion identification / warning systems	Train mounted computer collects data on WSP activity and transmits this with GPS location data to central computer. Provides effective real-time adhesion warning and feedback and post season analysis capabilities. Can be coupled with weather station monitoring.	AEA Technology developed 'LAWS' tested on Thames Trains during 1997 and 1998. No longer in use in other areas.
42	Weather stations	Local trackside monitoring stations measuring rainfall, humidity, dew point and temperature. Transmit data to central location. Can be coupled with low adhesion identification / warning systems.	Tested on Thames Trains during 1997 and 1998. Now widely used.
43	Lineside signs	Fixed retro-reflective signs erected to mark the approach of high risk sites.	Effective in providing drivers with reminder of high risk sites and

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		Illuminated signs switched on only when low adhesion conditions likely or experienced (PADS™).	reducing delays by advising only when conditions are poor.
44	Ceramic particle jetting	An alternative to trainborne sanders. Jets ceramic particles at high velocity.	Likely to be better for high speed applications than sanders. Tests by AEA Technology and German Railways revealed little adhesion improvement and less than achieved by standard trainborne sanders.
45	Abrasive blasting	Blasting of abrasive particles of various types to remove railhead contamination.	Tested by Network Rail as an emerging technology in 2003, not adopted.
46	Friction modifiers	Various types that can be applied by track mounted dispensers, train systems or hand application. Centrac HPF, Syton P, Ludox, ethyl caprylate, Portec solution, tertiary butylamine solution, colloidal silica fluids, sodium metasillcate solution, Kelsan HPF and TrackGlide sticks evaluated. Tested extensively by BR Research. Network Rail tested Keltrack friction modifier and Kelsan friction enhancer.	No real success (except Sandite). Can reduce adhesion if applied too liberally. Products developed mainly to reduce high friction.

47	Low adhesion site marker	Automatic dispenser to mark start of low adhesion site by passing trains.	Evaluated in 2003. Not considered practicable as marker would need to be laid at early braking point not start of low adhesion. Likely to remain visible when site no longer a problem leading to unnecessary delays.
48	Low adhesion prediction systems	Automatic prediction systems to alert control staff (and ultimately drivers directly) of oncoming low adhesion conditions. Able to target problem locations in real-time and minimise delays.	Adhesion Controller's Condition Assessment Tool (ACCAT) in use on Central Line for ATO authority. AWG developed and trialled a mainline version of ACCAT on Chiltern Lines but not adopted by industry. Part of a total Adhesion Management System.
49	Dimanin®	ProRail experimenting with a fungal contamination killer called Dimanin® which is sprayed onto the railhead at 'shadow spots' on the rail, where moisture and algae grow.	Two regions tried this during 2006-08 and reported some good results, but no definitive results were found.
50	Service Train Adhesion Modifier	Railhead treatment equipment fitted to standard service train, laying either Sandite or TG60. Controlled automatically by train	Experimented with by Network Rail and Greater Anglia railway during 2010-2012, operating out of the Smethwick and Cambridge depots.

		location equipment over pre-planned sites.	Concept moved to trialling on multiple units in service during autumn 2013-2014, reducing reliance on special treatment trains. The trials out of Smethwick continued through autumn 2017. Yet to be deemed successful.
51	Microwave railhead cleaning	Microwave superheated steam railhead cleaning system, pioneered by the University of Liverpool.	The concept successfully cleaned a simulated railhead using microwave generated superheated steam, but only at 2.5kph. The second phase saw development of a 40kph rig, and testing took place at the University of Birmingham on a rotating track test facility using a track coated with Lignin Floc to evaluate the system performance. No further development was sponsored by industry.
52	Effectiveness of surfactants for improving wettability and friction properties at the railhead (COF-TAR-04)	For tests on clean rail, Tergitol and Gum Arabic were observed to slightly increase friction when measured on clean rail.	As Gum Arabic fared similar to testing with water, Tergitol was taken forward to examine the effect this surfactant has when granite or grease is applied to the surface. However, the findings concluded that surfactants were not

			associated with changes in the friction of the railhead surface when compared to tests with water.
53	High resolution 'Internet of Things' moisture detection system (COF-TAR-01)	Developed low cost (<£100) self-contained moisture sensors that successfully identified wet and dry periods under both laboratory and field conditions.	Low-cost moisture sensing can be used to communicate data in real-time as part of an adhesion management system.
54	Non-contact ultrasonic cleaning to address the Adhesion Riddle (COF-TAR-02)	Examined the efficacy of a low-pressure water jet enhanced with ultrasonic technology to remove contaminant on the railhead using two technologies developed by the University of Southampton: StarStream is a nozzle that allows ultrasound to be transmitted down a stream of liquid to clean the object. A second technology designed to clean by generating ultrasound within a thin layer of liquid on a surface, substantially reducing water use.	The methods were found to be effective at completely cleaning laboratory and field generated leaf film from railhead while using lower volumes of water. The next step would be further field, but there are currently no plans to progress.
55	Use of Dry-ice for railhead cleaning (COF-TAR-03)	Investigated blasting with dry-ice to achieve railhead cleaning, and reduce the impact of 'wet-rail' – on	Small and full-scale testing suggests braking performance could be improved. Although full removal of

		the assumption that pellets of dry-ice coming into contact with a contaminant layer would cause the contaminant to cool, crack and subsequently de-bond, with further bombardment removing it.	a leaf layer was not achieved, it was proposed that with multiple passes or higher pressure blasting this would be possible.
56	On-board detection of low adhesion	Loughborough University carried out modelling, funded by RSSB, to investigate a system that would measure dynamic response and enable service trains to report locations of low adhesion, independent of whether the train is braking, coasting or motoring (T614 and T959).	Funded by Innovate UK in 2016, TRL carried out measurements on one Class 159 wheelset to see if this could be applied in practice, taking a simpler approach by fingerprinting axle behaviour to identify times and locations with low adhesion. The technique showed promise, but more detailed investigation is required on artificially simulated adhesion.

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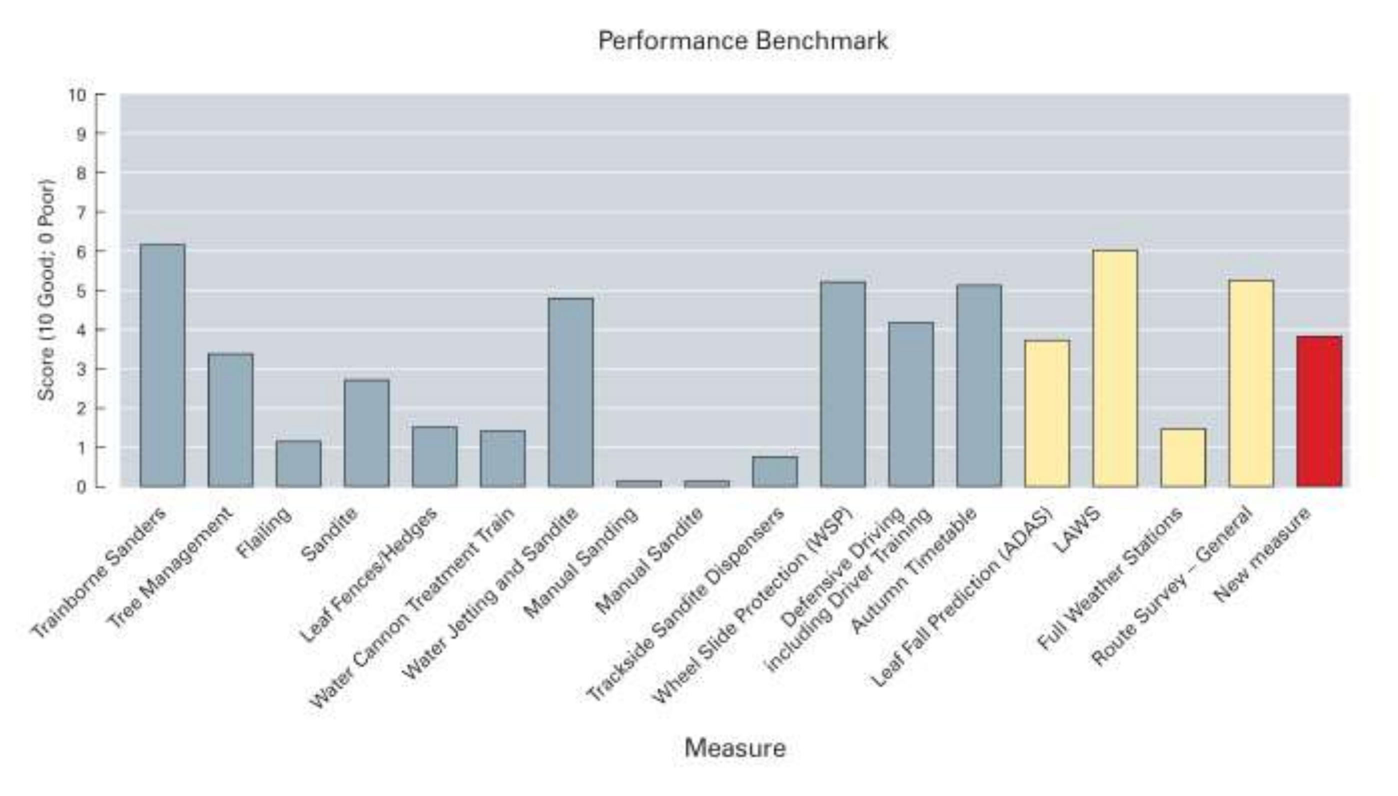
Evaluating new initiatives

AWG has 'benchmarked' the current adhesion control measures in order that the potential benefits of new adhesion control initiatives can be assessed by comparison against control measures already tried and tested and in use. This was primarily to aid AWG and the industry in its decision making. The benchmarking exercise has been completed in the form of an evaluation model called the New Control Measure Assessment Model.

The benchmarking tool includes trainborne sanders, vegetation / tree management, flailing, leaf fences / hedges, water jetting / friction modifier, manual sanding, Traction Gel Applicators, Wheel Slide Protection (WSP), defensive driving (including driver training), operating an autumn timetable, leaf fall / low adhesion risk prediction, trainborne low adhesion feedback, weather stations and route surveys (the last four items being 'information' systems but included for completeness).

Each control measure is assessed against five main criteria: performance, cost, safety, practicality and environmental, assuming a baseline of 1000 route miles, with 10% affected by low adhesion, a 15-minute average route traffic density and 100 train units operating across the route. Under each of the five main criteria are a series of relevant questions which had a scoring system dependent on the category. For example, under the performance category "other than effects due to adhesion, what is the performance impact of the measure (e.g. running an extra cleaning train)?" (score between 0 and 4) and under the safety category "what are the risks associated with infrastructure damage?" (scored by frequency and severity). This resulted in a 'benchmark score' for each control measure in each of the five categories, an example of which is shown below.

The grey bars in the chart below represent the scores for existing adhesion control measures, the yellow bars represent the four 'information' systems and the red bar is the 'performance benchmark' score for a 'new measure' under evaluation. The new measure is evaluated using the same set of questions and scoring matrix as applied to the benchmark control measures. The evaluation model, whilst not providing a statistically significant output, offers a simple way of performing a 'first cut' review of new ideas put forward, which when combined with the views of subject matter experts, will lead to the best use of the industry's resources.



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A7 Template press pack

AWG's leaf fall press pack is intended to provide a comprehensive guide for the media on the issues surrounding the autumn leaf fall season. It answers the key questions the media raise most years, from how a few leaves can stop a train, to the many tools and procedures the railway has developed to combat this perennial problem. This is intended for the general media and thus does not go into technical detail and also assumes no railway knowledge among the readership. It is approximately 3000 words long, but is written in a modular style so that users can extract information relevant to their local situation.

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A7.1 The problem: how can leaves stop trains?

Leaf fall is a universal problem affecting railways around the world. It starts when leaves fall or are blown onto the tracks. They don't have to settle on the actual rails to cause problems. When a train passes, the slipstream blows the leaves around and some get drawn into the 'nip' between the wheel and rail and are rolled onto the railhead. Although the leaves are turning brown, they still contain moisture and the rolling action has two effects.

- First it creates a layer of organic material across the head of the rail. But because each wheel of a passenger coach carries a load of around five tonnes acting on an area the size of a five pence piece, a pressure of around 30 tonnes per square inch is generated.
- This pressure compresses the leaf material, squeezing out the moisture to form a hard surface. When damp, this layer will have similar properties to the non-stick material used in frying pans. Each time a train passes, more leaves are rolled onto the rail, making the coating thicker and harder. It is this coating that can cause problems for trains, not only when braking, but also when pulling away from stations.

Weather conditions affect the severity of leaf fall. The worst case is a damp summer and autumn with an early sharp frost followed by high winds which causes leaves to fall before they have withered.

Some science

Railway engineers call the friction between steel wheel and steel rail 'adhesion'. It represents the percentage of the weight of the train that is available for braking. A motor car with warm tyres on a high friction road service can get close to 100% adhesion. This means that the braking force equals the weight of the car – the maximum that can be achieved. But a sudden shower on worn tarmac after a dry spell can reduce adhesion to a tenth of the maximum. This would be called 10% adhesion.

With steel wheels running on steel rails, adhesion is limited to the friction of metal rubbing on metal. Under good conditions heavy freight trains can work at 40% adhesion. But when calculating braking performance railway engineers have to allow for average conditions. Most passenger trains now have disc brakes with anti-skid controls. Even on wet rails, emergency braking can achieve >12% adhesion. But with passengers walking along trains, using this

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maximum braking routinely could cause falls or spills. As a result, service brakes are normally set to work at a maximum of 9% adhesion. Hence, under normal adhesion conditions trains have plenty of stopping power in hand.

However, during leaf fall, rails with nature's non-stick coating of moist compressed leaf fibre can give adhesion of between 1% and 5%. This is when the leaf fall problem starts.

When the brakes go on

Older trains had brakes with metal blocks pressing on the tread of each wheel. This kept the tread clean and helped reduced the effects of leaf fall – but only at a price. The brake blocks removed leaf fibre from the wheels, but if the wheel locked up and started to slide, the braking systems could not react fast enough. As a result, the locked wheel slid along the rail. With a pressure of 30 tonnes per square inch, even steel wears and the result was a worn section on the wheel called a 'flat'.

In the 1960s and 1970s, one of the main tasks during leaf fall was replacing wheels with flats. Stocks of wheels were prepared over the summer and during the two or three weeks of leaf fall the maintenance depots spent much of their time changing wheels. Today, electronic equipment in the brake systems, senses that a wheel is about to lock up and slide and releases the brakes on those wheels immediately. It then reapplies the brake with less force. If the wheel still wants to skid, the process is repeated.

In a long train, the effect of the wheels at the front will gradually clear the railhead so that wheels at the back may be getting normal adhesion. But under really low adhesion, a train can just skid.

Low adhesion works both ways. A train on slippery track will also find it difficult to pull away.

How it affects the passenger

If adhesion is very low, trains find it hard to pull away and may not be able to reach their normal speed between stations. Once the train is running, the driver has to compensate for the reduced adhesion and allow a much longer stopping distance. Journeys therefore take longer.

The worst affected trains are short trains (of two or three cars) making frequent stops. This is why commuter services are hardest hit by leaf fall.

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Inter-city trains are longer, with typically eight to ten carriages plus one or two locomotives with twice the weight on each wheel, and stop less frequently. They are thus less affected by leaf fall. Main lines are also more likely to run through open country compared with suburban routes.

Is it a new phenomenon?

With the replacement of steam power by diesel and electric in the 1960s, maintenance of the lineside changed. With steam locomotives there was a constant risk of sparks from the chimney setting trackside vegetation on fire. To prevent this, track maintenance gangs kept the lineside clear of vegetation.

With the demise of steam, lineside clearance was not deemed necessary. The only reason to control lineside vegetation was if it obscured the driver's view of the signals. Now, 50 years later, there are mature trees beside the railway. 20 years ago, a study estimated that along the 3,000 miles of the commuter network south of the Thames, there were 60,000 large trees close enough to the line to obstruct the tracks if they fell. A mature tree drops 10,000 to 50,000 leaves each autumn.

Is it just in Britain?

Railways and trees are the same the world over. In North America the colourful leaves during the Fall are a tourist attraction. But for commuter train operators, such as those around New York, the Fall is the 'slippery rail season'.

In 2003, a team from the Netherlands Railways made a fact finding visit to Britain to see how we dealt with leaf fall. This followed major disruption due to leaf fall in the Netherlands in the autumn of 2002, particularly following the severe storm of 27/28 October which also hit British train operators hard. What affected the railways in the Netherlands after the storm was a shortage of trains because of the need to withdraw rolling stock for wheels with flats. They were shortly followed by a visit by German railways who had suffered similar problems in 2002.

A7.2 What is being done about it?

With a problem like leaf fall, there are four things that can be done:

- reduce the problem at source by removing the root causes;
- take preventative action on the trains and track;
- because it cannot be eradicated completely, try to minimise the impact on travellers;
- be prepared.

Removing root causes

Good practice is to have a five metre wide strip cleared of trees and bushes each side of the track. Apart from reducing the impact of leaf fall, it prevents encroaching vegetation from obscuring the driver's view of the line ahead and reduces the likelihood of trees or branches falling across the track during high winds.

At the outer boundary of the five metre strip slow growing shrubs may be retained because they help trap fallen leaves.

Under the same 'vegetation management' programme, trees and shrubs are also cleared from along the boundary fence of the railway to allow inspection and maintenance and also protect lineside properties from falling trees.

Some trees, such as sycamore and ash, are fast growing and their leaves cause especially severe problems. These will be either thinned or felled.

Felling is a sensitive issue where trees have grown to form a barrier between the railway and its neighbours. While some felling may be unavoidable because of the safety implications, the visual impact can be lessened by thinning vegetation to form a series of overlapping chevrons at an angle to the track so that the screening effect is maintained. There is also the option of re-planting with more railway-friendly trees such as conifers or small- leaved deciduous saplings.

Coupled with reducing the number of leaves from lineside trees, it is also possible to deter them accumulating on the track. Low shrubs and brambles at the edge of the five metre strip can provide a natural barrier to windblown leaves.

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In locations where leaves accumulate – for example in cuttings – fences at the trackside can stop leaves from getting close enough to the rails to be picked up in the slipstream.

Preventative action – on the trains

Modern trains have disc braking systems which make the very best use of what adhesion is available. But they can't use adhesion that isn't there if the track has a slippery coating of contamination.

A valuable tool in the fight against leaf fall has been the revival of on-train sanding, common on steam locomotives. To improve adhesion a fine stream of 'sand' is blown onto the rail in front of certain wheels. Today's 'sand' is, in fact, a carefully formulated mixture of abrasive material that has to be fine and dry enough to flow easily in a jet of air from large containers on the train through a pipe aimed at the nip between wheel and rail.

These sanders are linked to the brake control system. If the control system detects that a wheel is starting to lock-up – or 'slide' – sand is applied automatically. As the wheel runs over the abrasive sand, it cuts through the film of leaf fibre to the steel underneath, restoring adhesion.

'Smart' sanding takes this concept a stage further and matches the quantity of sand applied to the level of braking demanded by the driver and the speed of the train – the faster the train is going and the heavier the braking the more sand it will require. This reduces the risk of a train sanding heavily as it passes over points at slow speed, leaving sand in the working parts of the points.

Helped by funding from the government and Network Rail, the railway industry has fitted sanding systems to virtually all existing fleets of diesel and electric multiple units.

Preventative action – on the track

This comprises two activities:

- Removing contamination – ideally the coating on the rails should be removed before it can cause a train to slide. There are several tools available to do this. One of the most popular is high pressure water jetting equipment which is mounted on the Rail Head Treatment Trains (RHTTs). While the compressed leaf material is at its slipperiest when damp it will soften when wet. Water jetting at very high pressures, up to 1500 bar, blasts the surface back to clean steel. Effective removal can be achieved with the RHTT running at up to 60 mph. These specialist units are deployed across the network to cover sections of track with a high risk of contamination. Of

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course, after the water jet has passed, the leaves will keep on falling. When leaf fall is at its height, track maintenance teams can be sent to the highest risk locations, equipped with portable scrubbers, to clean the railhead.

- Improving adhesion – cleaning the railhead is a slow process and has to be concentrated at known trouble spots. But leaf fall contamination can build up across a wide area and to minimise the impact the long-standing solution is to use a friction improver such as Sandite or Traction Gel.

These are best described as being like sand mixed into wallpaper paste – although it is much more advanced that that – for example incorporating tiny metal particles. RHTTs have large tanks of the product which is pumped to nozzles above each rail. As the train passes along the track it leaves a layer of the gel on the top of each rail.

If there is leaf fall contamination on the railhead, the following trains grind the gritty gel into the hard surface breaking down the leaf film and providing grip. Sandite continues to develop, with a range of formulations for different applications.

When leaf fall is expected, RHTTs start running to a schedule which maximises coverage of known problem areas. By combining water jetting with the application of friction improver, the rail is cleaned and left with a coating of the adhesion improving gel. However, each train that follows thins the layer and eventually the effect wears off and new contamination starts to form. At locations where contamination is known to be heavy, additional treatment can be provided.

At some remote locations automatic static friction improver dispensers are installed. These have nozzles which inject a pre-set amount of treatment onto the rails rail just before a train passes, the wheels of the train carrying the gel along the track.

Another option at known problem spots is the handheld treatment dispenser. This is like a walking stick with a handle at one end and roller, which rests on the railhead, at the other. Mounted on the stick is a container of friction improver. A trigger on the handle releases the gel as the operator pushes the dispenser along the rail.

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Reducing the impact

Despite this wide range of measures, trains will continue to experience low adhesion. Safe operation then depends on the driver. While train driving simulators can demonstrate the effect of low adhesion, there is a difference between simulation and the experience of sitting in the cab of a train and driving when the wheels are struggling to grip.

Some train operators provide drivers with this real life 'skid pan' training during the summer. A multiple unit is fitted with equipment to spray a mixture of water and detergent on the rails, or to moisten a special paper tape stuck to the rails. This reduces adhesion to the low levels experienced during leaf fall. Running on either a protected section of track or a preserved railway, drivers can then be shown the best driving techniques to deal with low adhesion and the effect of sanding, and practice their techniques.

In addition, during leaf fall what is known as 'defensive driving' is implemented; braking earlier and lighter. This anticipates low adhesion when approaching signals and stations, and recognises that even on a route with normal adhesion, there may be localised areas affected by leaf fall.

Inevitably trains will take longer to compete journeys during leaf fall. This can lead to progressive lateness during a journey and leave insufficient time to turn around before the scheduled departure of the train's next journey. To minimise the risk of such 'knock-on' delays, some train operators introduce revised timetables for the leaf fall period. These add extra time between stations to allow for slower running and also give more generous turn round times at terminal stations. The aim is to produce a service, which while slower, can be relied on by travellers.

Be prepared

Leaf fall is critically dependent on the weather, so Network Rail and train operators are able to draw on the most detailed and specific weather forecasts tailored to the railway's requirements. They will enable the mobile resources and RHTTs to be scheduled during the period when the critical combinations of weather conditions which initiate or exacerbate leaf fall are developing.

But even when leaf fall has started, 'smart' trains can alert local controllers when low rail adhesion is detected. On-train computers with their own mobile phone and satellite navigation system, can monitor the brake control system. If it is detected that the wheels are trying to lock up when braking, or spin under acceleration, it analyses the data and

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determines the severity of the low adhesion. This information, together with the location of the train, can be sent by phone to a control centre where data from the trains is recorded and the sites displayed on a map of the rail network.

This real-time reporting means that the development of low adhesion sites can be monitored, together with severity, allowing these sites to be targeted by local teams with hand held scrubbers and railhead treatment dispensers. RHTTs can also be alerted to new sites needing treatment on their scheduled routes.

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A8 Sources of contamination

The following is extracted from a BR Scientifics report commissioned by AWG: TM-MSU-408 "Rail Contamination and its influence on Wheel / Rail Adhesion", IJ McEwen, January 1999.
Formatting has been updated and some sub-titles added to improve readability.

The forces which govern traction, braking and steering etc. of railway vehicles are all transmitted through a very small area of contact between the wheel and the rail. The geometry of a wheel and rail in contact is very complex because of the profiles, angles and displacements involved but the contact can be regarded in most cases as being about the size of a 5p coin. A close look at the head of a typical rail on well used mainline track reveals a central shiny wear band where this contact takes place, often bordered by heavily rusted shoulders. Although the wear band can often appear very clean and shiny, it is a fact that all rails are contaminated to some degree.

The small amounts of oily material and other debris found on the running band of the average rail ensure that the very high levels of adhesion coefficient μ found in the clean conditions of a laboratory environment are not seen in railway practice. Studies carried out in the 1970s on a variety of railway routes with different traffic types showed that these typical contaminants, even though present in minute amounts, can have a profound influence on adhesion.

Sources of Contamination

It is widely known that the weather influences adhesion. In reality it is the presence of water which is chiefly responsible for this influence, either as different degrees of precipitation (heavy / light rain, snow, drizzle, etc.) or the combined effects of temperature and humidity to trigger condensation on the rail. Thus in setting up any list of rail contaminants we can start with water as the most common of these. In constructing the following list the source of the contaminating species has been considered since, in cases of low levels of material on the rails, the source may be more obvious than any film on the rail. Remember also that the source may be outside the railway environment.

Water

Water, as in steady rain, is often said to be a great leveller in adhesion terms. High adhesion on dry rails will invariably be reduced by the onset of rain but typically only to a level of μ = 0.2 to 0.25. The corollary to this is that in certain low adhesion situations rain will lead to a raising of adhesion – hence the description the great leveller. The influence of rain is the main reason that average adhesion levels are lower in winter than in summer. Because the assumed levels of adhesion set by the design engineer for traction and braking needs are conservatively low, wet rails in general pose few operating problems.

It is when water is present in only small amounts on the rail that its major influence can be seen. This may be in very light drizzle, on a misty or dewy morning or as wet rails begin to dry out. In these circumstances μ can fall to below 0.1 on otherwise clean rails and, in combination with overnight rusting, levels down to 0.05 have been measured. It is this naturally occurring combination of small amounts of moisture or damp rails with rust or some other form of solid debris present that leads to some of the most problematic adhesion conditions. As we shall see later, the fact that very low adhesion can depend upon there being a critical amount of water present, such effects are fortuitously often short lived, the passage of only a few axles being sufficient to disturb the equilibrium.

Rain can obviously affect significant lengths of track as can dew or other condensation effects. However there are situations where the effects of moisture can be very localised, for example in short cuttings where the late autumn sun being low in the sky casts shade on the rails producing 'microclimates' which can encourage condensation. Similarly a distinctly different source of moisture as overspray from the sea or from industrial / agricultural processes (cooling towers, crop spraying etc.) can produce site-specific occurrences of reduced adhesion. Overspray from railway weed killing operations has also in the past been recorded as leading to traction problems for trains on adjacent lines.

Finally in this section the flushing of passenger train toilets can leave behind wet rails, assumed to be 'water'. The feature is relatively short lived and the rails may even dry before the next train. However, most modern trains now have retention toilet tanks thus this source of water is much less significant now.

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Ice / Snow

Almost all the foregoing facts on water and its influence on adhesion will apply to ice and snow on the railhead. It is not possible for traction stock to 'skate' on an iced rail since the thin film will readily break up under wheel action and be removed from the rail. However the thin film of moisture left behind or the damp conditions created by the melting of a light snowfall can adversely affect adhesion, particularly on a rusted rail.

Oily Matter

Sticking with fluid contaminants, oil is the next most common rail contaminant. Special exercises have been carried out to determine the amount and nature of the oil collected from the running band of the railhead. On average the oil coverage is of the order of only 10^{-6} g/cm^2 which is equivalent to a film of about 5 molecules thick. As will be discussed later even these minute quantities will influence adhesion just as any lubricant lowers friction.

The sources of the oily matter found on the rail are fairly obvious. Oil drips from the undersides of vehicles as well as coming from the lubrication of track components. Probably more so than with any other contaminant, the presence of oil can be extremely localised, as for example by a signal where locomotives are often called to a stand or, in the extreme, in a single drip from a moving vehicle. However under the action of passing wheels the oil will tend to spread into ever thinner films as it gets transferred along the track. What is probably not so obvious is that such thin oil films, under the extreme pressures of passing wheels and the action of sunlight, rapidly oxidise and take on a more 'polar' character. As such they may well become better boundary lubricants than the oils which first find their way onto the rail.

An extreme source of oil contamination comes about when a vehicle suffers a significant oil spillage, as for example might occur with a burst hydraulic pipe on a track machine. In such circumstances it is important to commence clean-up operations as quickly as possible since the oil can spread for significant distances under the action of traffic. This topic is covered later.

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The description oily matter is used to describe a host of different materials, the more common ones being briefly described in the following paragraphs:

- Grease – the most common source of grease contamination of rails comes from badly adjusted trackside flange lubricators. Just as the position of a flange lubricator can often be picked out from a distance because of the adjacent soiled sleepers and ballast, so a badly adjusted lubricator can readily be identified in a tribometer train adhesion profile due to the dip in adhesion.
  The use of PTFE containing grease may mean that the visual clues confirming contamination are not so obvious in comparison with traditional black graphite and molybdenum disulphide greases.
- Fuel Oil – fuel oil spillage is common in, for example, the first heavily canted curve away from a refuelling point. Fuel oil is not a good lubricant but after evaporation of the lighter fractions and oxidation on the rail may affect adhesion adversely. It is, however, unlikely to produce any serious problems in adhesion terms.
- Aviation Fuel (Kerosene) – there have been several reports of occurrences of low adhesion near to airport flight paths being caused by 'dumping' of aviation fuel or non-intentional spraying of unburned aviation fuel by aircraft coming in to land or taking off. Without doubt it is true that the smell of kerosene can sometimes be detected but it has not been seen as liquid fuel 'rain' at rail level.
  As with fuel oil from railway power units, aviation fuel is unlikely to produce serious adhesion problems in the unlikely event that it does find its way on to the rails.
- De-icing Fluids – de-icing fluids used on third rail track in winter (or more accurately 'ice parting compounds') may have an oil base and have been known to find their way to the running rail by overspray / splash. Although not a common thing such contamination could be a cause of low adhesion.

Solid debris

All rails have small amounts of solid debris on the running surfaces – most commonly a mixture of corrosion products from the rail, wear debris and brake block dust. However, the many different solid contaminants found on rails (as opposed to the naturally occurring 'rail debris') and their sources are probably more diverse than the fluid materials already described. In contrast to oily matter, however, the influence of the dry solid particles found on rails is minimal in adhesion terms. It is only when water is present, and then in critically small amounts, that the influence of solid particulate matter shows itself more strongly. Two extreme exceptions to this rule would appear to be sand and autumn leaves, although the latter are significantly worse when damp than when dry. The more common types of solid contaminant are described in brief detail below:

- Rust – the shoulders of the railhead can be seen to be heavily rusted but the apparently clean central wear band also has a light covering of rust particles. These are a complex mix of iron oxides and hydrated iron oxides and under a microscope appear as conglomerations of sub-micron sized particles, often of a plate-like nature due to the compression under passing wheels.
  The heavily rusted areas of the rail can act as 'sponges' to provide reservoirs for oily matter dripping onto the rail; the particulate rust on the wear band, because of its high surface area can similarly 'mop-up' oils by adsorption.
  The most significant effect of rust on adhesion comes about when it is combined with small amounts of water as described in the next section on mechanisms of lowering adhesion.
- Leaves – by far the most well known influence on wheel / rail adhesion, because of media coverage, is the autumn leaf. This phenomenon of leaf films on rails leading to such extreme problems is full of surprises, even to railwaymen of long standing.
  Leaves do not, of course, simply fall onto the rail to be trapped by passing wheels – this would be an extremely slow process in building up the continuous black films that can be seen in autumn. Leaves on the track are whipped up in the turbulent slipstream effects of passing trains and get caught under the wheels and 'rolled in' to the rail. Experiments with simulated leaves spread out in the track have shown that one 8-car multiple unit can pick up as many as 60% of the leaves present in the 4' and deposit them on the rails. The leaf-like character then very quickly disappears under the action of passing wheels and in the right conditions a black thin continuous film is formed which completely obliterates the shiny wear band. The term 'leaf mulch' which is sometimes used to

describe these films is very misleading and does not at all describe the matt, black, very tenaciously held coating so often seen. The film can be as difficult to scrape from the surface with a sharp blade as would a black paint film. It can readily be seen that with established leaf films metal-to-metal contact is lost between the wheel and the rail and track circuit continuity will be affected. Also the onset of light rain or drizzle results in very slippery conditions with some of the lowest adhesion levels ever measured (μ down to 0.02). Indeed water plays a very complicated role in leaf affected track. The onset of heavy rain will soften the leaf film just as a paint stripper might soften and lift a paint film; the action of passing wheels can then remove the film as quickly as it formed in the first place. Similarly, heavy rain helps to prevent leaf film build-up since the soggy leaves are less mobile in the slipstream air currents and the leaves do not stick well to wet rails. Thus excess water is of benefit in the fight against autumn low adhesion whereas drizzle or dampness can produce the most disastrous conditions.

Finally in this section on leaves comment should be made on a feature not widely appreciated. Tribometer train adhesion profiles of a long tree-lined cutting in late autumn showed an immediate drop in adhesion on entry to the cutting but a very slow and gradual rise on exit, in spite of there being no visible evidence of leaf film carry-over. It was shown that the 'leaf juices' squeezed out from fresh leaves by wheels gets carried down the track just as other oily contamination does. Thus adhesion can be affected for a half mile or even more after the obvious source of leaf contamination has been passed.

- Sawdust – this is a very site-specific contaminant and can come from tree clearance schemes on the trackside or from industrial sawmills etc, although extraction and collection plant makes this very rare these days. Blowing sawdust can stick to wet or damp rails and get rolled in under the action of wheels. Because of its cellulosic nature sawdust affects rails in much the same way as leaves although its influence is usually very localised.
- Solid / Particulate Cargo Spillage – railhead contamination with powdered coal is fairly common on merry-go-round routes, particularly in the first mile or so of track after unloading. Dust and small coal fragments settled on the frames of the hopper wagons drops off onto the rails, sleepers and ballast. The influence of dry coal dust on adhesion is usually slight but when mixed with water to form a thin slurry can give a short lived fall in adhesion sufficient to cause traction if not braking problems.

  Iron ore pellets and the associated dust have also been known to produce heavy contamination of the rails and track in certain locations. The influence on adhesion is similar to that of rust, small amounts of water combining with the ore dust to lower adhesion.

Clay slurry dripping onto the rails from cement works traffic has also at times given rise to slippery rails although the dried out clay can give rise to an improvement in adhesion by acting as a large surface area sponge for oils. Cement spillage in damp conditions has been known to give adverse adhesion trends although, again, the finely divided dry powder can in some cases benefit adhesion by mopping up excess oily matter.

- Salt – common salt, whether as a spillage of rock salt or as dried out sea spray or mist, is often cited as a cause of low adhesion conditions. There could well be a two-fold effect at play here. Just as table salt in a salt cellar may become damp so crushed rock salt or deposits from dried out marine spray will attract a thin film of moisture. This, coupled with the accelerated rusting of the rail, may give just the right mix of solid material and moisture to produce a low adhesion.
- Sand – sand is the odd man out of the long list of contaminants to be found regularly on rails in that in almost every case **sand will raise adhesion** when first it comes between the wheel and the rail. Dry sand from whatever source (blow-over from seaside dunes or stockpiles, spillage from freight vehicles) is unlikely to stick to the rail unless other contaminants are present (water, grease, etc.) and thus in most cases any sand present will have been specifically applied for adhesion improving purposes. Once caught in the wheel / rail nip the sand particles will become crushed but will also be ‘ground in’ to the rail surface sufficiently to last for the passage of several axles but probably not several trains. Because of the shape and hardness of the particles, sand ‘keys in’ to the two moving surfaces and imparts a grip not seen with other softer particulate contaminant matter.

Sand mixed with gels can be used in special Rail Head Treatment Trains. The viscous fluid component of the mixture helps to stick the sand to the rail and any excess material pushed aside by wheel action remains on the shoulders of the rail for pick-up by later slightly displaced wheels. Thus it tends to have a much longer lasting effect than dry sand and improvements in adhesion have been measured many hours after the treatment was laid. It is worth remembering, however, that because the sand is present with approximately equal amounts of water, application may in cases of very high initial adhesion give a temporary fall in μ due to the overriding effect of water. This lowering will never be problematic and must be balanced by the improvements in adhesion seen when this is initially low.

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The above list covers the main contaminants seen on rails in the UK but it is true to say that all foreign material will influence wheel / rail adhesion in some way.

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A9 Autumn investigations

This appendix describes the results of various analyses into low adhesion undertaken to assist in identifying the root causes, the extent of the problem and the effectiveness of control measures. The analyses were conducted in 1999, 2003, 2005, 2006, 2010, 2013 and 2016 and hence present an historical assessment. The results of the various analyses provide a range of lessons for the whole industry, but **it is emphasised that these are historical analyses not necessarily reflecting current performance or issues**.

A9.1 Project NADIR 1999

In 1999 a large data gathering, and analysis project called NADIR was undertaken in GB. The basis of the project was the collection and analysis of data relating to train operation, delays, delay reduction initiatives and weather conditions through the months of November and December 1999. The data related to 18 routes selected as being nationally representative, e.g. known for having low adhesion problems and applying various adhesion initiatives. This included a management and human factors study looking at train operator adhesion management policies, organisation and culture, and the training and competence of drivers in dealing with low adhesion.

What happened in 1999?

The analysis showed that rather than the expected decrease in operational delays during the autumn of 1999 when compared to the previous autumn, the number of train delay minutes increased by 6.5%. Notable points from the analysis were:

- autumn delays were 58% higher than summer time delays;
- the proportion of delays between passenger and freight trains was similar, with a 61% increase (compared to summer) in passenger train delays and a 58% increase in freight train delays (although part of this was considered due to the increase in freight traffic);
- delays directly attributed to leaf-fall accounted for 25% of the summer/autumn increase in passenger delays and 9% of freight delays. However, further analysis suggested that this may actually have been as high as 60% for passenger and 20% for freight;
- the increase in delays occurred in all parts of the country but to differing degrees;
- SPADs decreased, but station overruns increased as did wrong side failures of track circuits.

What caused this to happen?

It should be noted that the following factors that were determined to have affected train delay minutes may not equally have affected safety of the line incidents such as SPADs, overruns etc.

The review indicated three particular environmental influences had a significant impact on train delays: **gradient**, **rainfall** and **vegetation**. In addition, **human factors** and **train type** were also important factors.

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- gradient – using a level gradient as the baseline 'leaf-fall related delay minutes per mile index' of 1.00, the following factors were determined from analysis:
  - slight downhill gradients (no steeper than 1 in 100 falling) are just over twice as bad with an index of 2.05;
  - steep downhill gradients (steeper than 1 in 100 falling) are marginally worse at 2.13;
  - slight uphill gradients (no steeper than 1 in 100 rising) are again slightly worse at 2.2, and
  - steep uphill gradient (steeper than 1 in 100 rising) generate nearly four times the delays per mile as level track, with an index of 3.97.
- rainfall – using a baseline index of 'no rain in a 24-hour period' of 1.00. Compared with this baseline:
  - Low rainfall (0 to 5 mm/24 hr) increased delays by 1.28 (nearly 30% worse);
  - Medium rainfall (5 to 10 mm/24 hr) increased delays by 1.57 (nearly 60% worse), and
  - High rainfall (greater than 10 mm/24 hr) improved conditions to 0.91 indicating a 10% reduction in baseline delays.

  These figures backed up previous qualitative studies. The fact that delays reduce with heavy rain is considered due to the rain washing contamination off the rails. It is also interesting to note that medium rainfall gives rise to the greatest delay whereas the perception is that light rain gives the highest safety risk.
- vegetation – standard leaf-fall severity indices were used as detailed in section 4.4.2. Adhesion related delays were found to occur at three different levels:
  - Low Vegetation grade 1;
  - Medium Vegetation Grades 2, 3 and 4;
  - High Vegetation Grade 5.

  When compared to **low** vegetation sections of route, it was determined that a **medium** vegetation section of route produced on average 5 times more delay per train mile, and a **high** vegetation section almost 17 times more delay.

- Human Factors – the study found:
  - most train operators did not have specific policies for managing the autumn period but had an implied general policy evident through the implementation of initiatives;
  - briefing of autumn issues was better in some train operators than others. Some drivers received no briefing at all before the autumn;
  - professional driving techniques were not uniform;
  - changes had occurred to low adhesion instructions over the years leading to some confusion;
  - variations existed in training initiatives and in the adequacy of content;
  - reporting of lost time was poor as was the understanding of where the time was lost;
  - some timetables were unachievable in the autumn;
  - variations existed in working relationships between drivers and their managers. Those with better relationships often performed better;
  - poor communications occurred between drivers and signallers about low adhesion conditions and there was a lack of understanding of what ‘Exceptional’ conditions are.
- train type – there was qualitative evidence to confirm that short train formations were more susceptible to adhesion incidents.

Effectiveness of initiatives

- trainborne sanders delivered a significant reduction in the delay index identified above:
  - sanding for braking only on short disc-braked trains significantly reduced train delays;
  - sanding for braking only on longer disc-braked multiple units reduced delays but not to the same significance as shorter trains;
  - sanding for traction and braking almost neutralised any delay worsening due to adhesion, being up to 60% better than for unfitted units;
  - similarly, sanding for traction and braking on longer multiple disc-braked units delivered a major benefit by reducing the delay due to adhesion by up to 50% compared to unfitted units.

- rail conditioning:
  - where Sandite was applied it reduced adhesion-related delays on average by 35% over the following four-hour period;
  - in the absence of applying Sandite, delay on the sections concerned was on average 10% higher than other parts of the network.
- other Initiatives that showed some improvements but were not fully evaluated (mainly due to small sample sizes), including the lifting of Temporary Speed Restrictions; switching off flange lubricators; flailing; the Vortok Leafguard; and illuminated lineside signs marking adhesion blackspots when they were ‘Exceptional’.

Conclusions

The 1999 NADIR project concluded that each minute of primary delay reduction leads to a total passenger delay reduction of 6 minutes. The Cost Benefit Analysis undertaken led to the following conclusions:

- fitting trainborne sanders operating in traction and braking modes achieves the lowest unit cost for each minute delay saved and would eliminate 316,000 minutes (20%) of the increase in passenger train delay;
- the current Sandite programme is effective in avoiding nearly 150,000 (10%) of the autumn increase and its cost is roughly equal to the value of the delay avoided;
- a vegetation management strategy for dealing with level 5 vegetation sites could avoid 125,000 (8%) minutes delay again at a cost similar to the value of delay avoided.

Put together these measures were estimated to reduce the annual autumn delay increase by approximately 400,000 minutes (30%).

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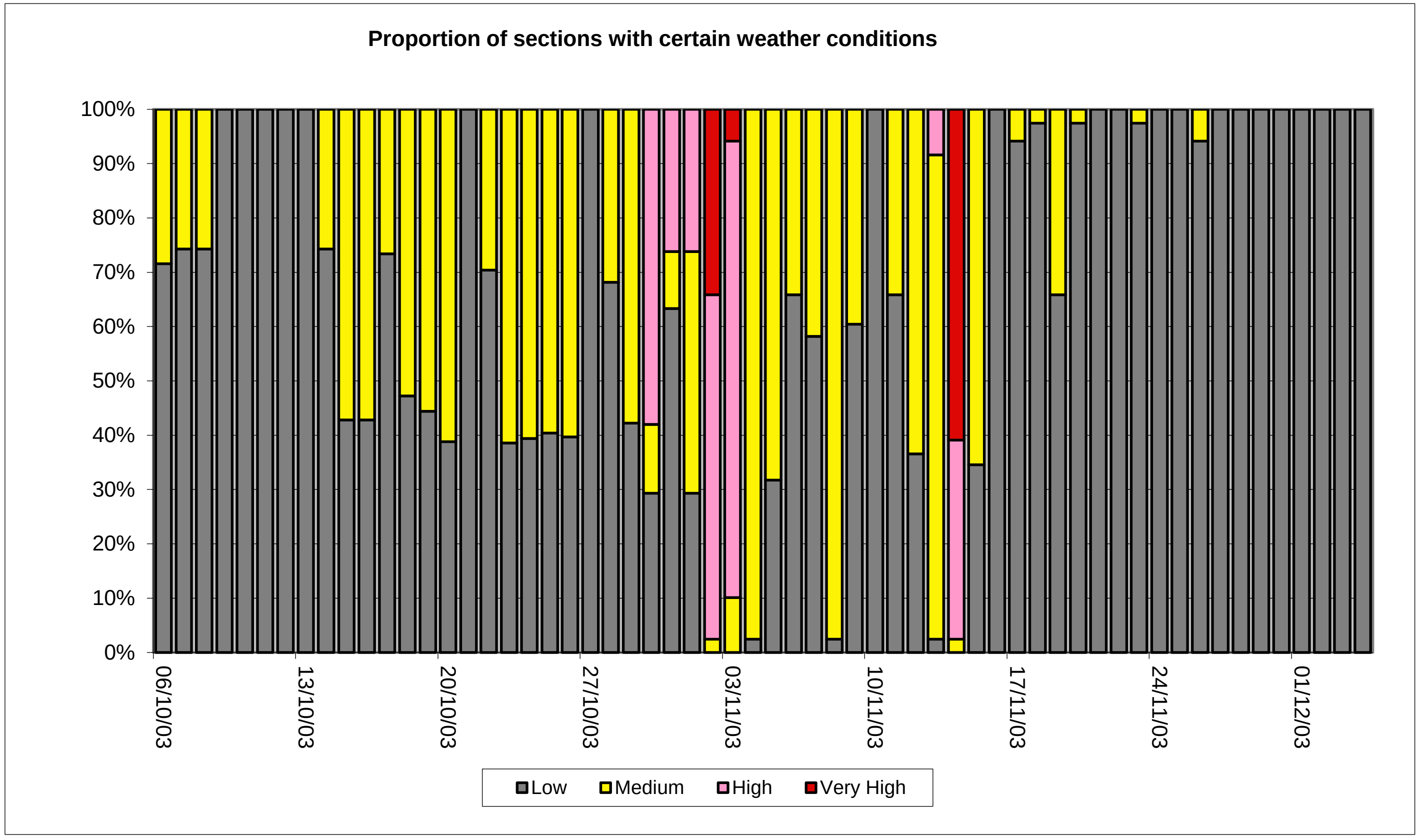
A9.2 Project NADIR 2003

In 2003, Network Rail repeated the NADIR exercise to establish whether the same factors were still evident. Performance was studied on the original 18 routes, together with three additional routes. In addition, the network as a whole was studied, but the totality was to a slightly reduced analysis scope, being mainly confined to studying the effects on passenger train operation. The main part of the project was to gather data on delays and other adhesion related events as they emerged and enter them into a database. Data was gathered from train operators and Network Rail, and site visits were made. The data was analysed, including undertaking cost benefit analyses, to provide answers to the following key questions:

- what happened to performance during autumn 2003 and how did this compare to 1999?
- why did these effects occur?
- how effective were the various delay reducing initiatives employed?
- what should the industry do as a result of the study – future strategy?

How did 2003 compare with 1999?

Autumn 2003 was relatively benign compared with previous years. There were only two days when the low adhesion risk index was 'very high' – 2 November and 14 November 2003. The weather index for each day of the autumn is shown in the chart below. Therefore, a large amount of the variation in performance across the network was believed to relate to normal periodic variations in incidents, rather than specifically autumn ones.



Overall, the performance impact during autumn 2003 on the studied routes was as follows:

- passenger train delay increased by 25% in the autumn, and a 29% increase in delay was experienced by freight, when compared to Periods 3 and 4;
- the increase in primary delay was less, 16% for passenger services and 24% for freight, indicating a disproportionate rise in the amount of reactionary delay (this difference can be anticipated as when a driver drives more cautiously the headway between train services increases and network capacity is reduced);
- over the autumn period, some 13% of services across the network operated to special timetables, with additional recovery time built-in to allow for poorer performance.

Why did these effects occur?

- Vegetation – a route-by-route comparison of the vegetation data (collected by cab survey) in 2003 compared to 1999, revealed differences in the percentages of route length assessed with each vegetation index. In some cases, the distribution for 2003 showed a higher vegetation index, whereas other routes showed a reduction in vegetation levels.

  The influence of different levels of lineside vegetation was examined based on the distribution of vegetation coefficients for each route section. The relative effect that different vegetation indices had on train delay is shown in the following table where the relative delay factor value shown for vegetation indices 2 – 5 indicate the factor of increase over the expected delay in a Vegetation Index 1 section:

Vegetation Index	1	2	3	4	5
Relative delay factor	1.0	1.0	1.6	4.5	1.8

  For 2003, the spread of delays compared to vegetation indices showed a different pattern to 1999. Indices 1, 2 and 3 tended to form the low vegetation group where the delay was less than twice the delay per train mile of vegetation index 1 locations. Vegetation index 4 formed the medium group with delays at 4½ times the vegetation index 1 level, and an apparently anomalous result was derived for vegetation index 5 sections which appeared comparable to vegetation index 3 (and may be explained by the actual delays recorded in such areas being less through thorough deployment of countermeasures such as Sandite / jetting and other local attention to detail).

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In terms of relative effects, it appears that areas of high vegetation were less of a problem in autumn 2003 than they were in 1999, but it was not possible to determine whether this was because of better preparedness in 2003 or generally better weather.

- Weather effects – the predicted weather effect was used in the analysis, combining temperature, wind and rainfall effects, being calculated daily by ADAS (a company specialising in predicting low adhesion risk from environmental factors). It was assumed that this would more accurately portray the likely reaction of the railway operator, in applying counter-measures, warning drivers and so forth, than the hindsight of actual conditions.
  Predicted 'medium' risk days experienced over twice the level of delays as 'low' risk days, and 'high' and 'very high' risk days were similar to each other with just over three times the delay experienced with predicted 'low' risk days. The value for 'very high' weather risk is based on a very small sample of days. As in the case of the extreme vegetation index delay value, the anomalously lower delay factor may be due to a specific reaction to very high risk by managers on the ground.
- Train type and braking system – analysis of train types was carried out, to determine whether there was a significant difference between generic types of rolling stock – diesel multiple units, electric-loco-hauled etc – and whether there was a difference between the basic brake types – tread or disc-braked. Based on diesel High Speed Trains (HST) having a value of 1.0, the following performance differences were identified:
  - locomotives exhibited fewer delays per train km;
  - disc-braked multiple units were comparable to the HSTs;
  - tread-braked multiple units were nearly five times worse that HSTs.

  The analysis was extended to compare the types of Wheel Slide Protection (WSP) equipment fitted to trains but the results were inconclusive. Although the results were difficult to interpret and differences between individual WSP types were at variance with expectations, deployment of WSP was found to reduce the delay per 1000km from 8.1 minutes with no WSP to 4.6 minutes with WSP, a reduction on fitment to 0.57 of the non-WSP fitted value.
  The analysis also confirmed that train length also influences delay, longer trains suffer considerably less delay than short ones.

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How effective were the various delay reducing initiatives employed?

- Trainborne sanders – three types of trainborne sander were analysed with the following results:
  - no trainborne sander averaged 7.5 mins delay per 1000km;
  - the Emergency One-shot sander 4.1 mins/1000km;
  - traction and braking sander 5.7 mins/1000km;
  - SmartSander™ (a type of variable rate sander) 4.3 mins/1000km.

  The result for the Emergency one-shot sander should be treated with some caution, as these were fitted only on Class 220/221 Voyager and Class 390 Pendolino trains. Other than for this factor, the results were in line with expectations.
- Railhead treatment – over two-thirds of rail-head treatment in 2003 consisted of water-jetting followed by Sandite application, a change from 1999 when there was virtually no water jetting, just Sanditing. The analysis consistently showed that delay for sections where water jetting and Sandite have been applied together, averages 48% of the delay in sections where no treatment was applied. The value of water-jetting plus Sandite was higher on days where weather conditions were worse.

  The contribution from Sandite application alone was to reduce the delay to some 80% of the non-treated value (compared to a reduction to 84% for Sandite alone from the 1999 analysis), although treatment with both Sandite-alone and water-jetting-alone in 2003 was not extensive enough to draw a reliable conclusion on their absolute values.
- Rail Grinding – analysis of the results shows no evidence that rail grinding has a positive effect in reducing delays caused by leaf film accumulation, either during the leaf-fall periods or in the eight weeks prior. This may be because grinding was only carried out on a small proportion of route sections, making the effect difficult to identify, or it may be due to the effect being there initially and then declining quickly as the rails again became smoother and more contaminated again. This apparent lack of effect was observed regardless of the type of grinding being carried out. Therefore, no particular conclusions can be drawn about the effects of rail grinding.

Conclusions

The key findings of the 2003 analysis were:

- high levels of **vegetation** surrounding the track increase the expected train delay. The influence of this factor was less marked than in the original 1999 NADIR study which could be because of the much higher numbers of trains fitted with an on-train sander;
- higher levels of **weather risk** increase expected train delay (note though the ADAS parameter used to examine this in the study was not directly comparable to the rainfall data used in the 1999 NADIR study);
- **railhead treatment**, now generally using water-jetting followed by Sandite application, continues to be a valuable method of reducing train delay. This general finding was similar to that in the 1999 NADIR study, although the introduction of water-jetting affects direct comparison;
- different levels of delay generated by **different rolling stock types** with different braking characteristics. Findings were in line with those of the 1999 NADIR study;
- **on-train sanders** were found to reduce delay significantly, with the SmartSander™ variable rate sander shown to be better than other classes of braking and traction devices, and braking-only devices. Findings are in line with those in the 1999 NADIR study.

The key conclusions from the 2003 study were:

- The analysis of autumn effects, and of the effectiveness of counter-measures, has been difficult because of a combination of reasons:
    - a very well targeted and executed plan for dealing with known problem areas, both before the autumn period started and during the autumn itself, in both railhead treatment and deployment of on-train sanders;
    - relatively benign weather conditions, with few occasions where heavy leaf falls occurred suddenly, and without many extremes in temperature, rainfall or wind.

Nevertheless, it has been possible to deduce some lessons from the data analysed:

- **vegetation levels** adjacent to the track influence the degree of delay, although the measure of the influence of sections with very high vegetation risk appears anomalous. It is suspected that this may either be because these

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high-vegetation sections do not generally coincide with a high braking or acceleration requirement, or that the high risk in such sections is recognised and addressed well by local managers;

- predicted **weather conditions** influence delay but again this effect is mitigated on very bad days;
- **treatment of the railhead** using a combination of water jetting followed by Sanditing appears to be very effective in reducing expected delays to 48% of their value without treatment, and the outline cost-benefit case for this treatment is still strong;
- **rail grinding** was not demonstrated in the study to be an effective treatment for autumn adhesion effects;
- train **vehicle characteristics** were examined, and the relative value of tread and disc brakes and different WSP devices were estimated;
- the effectiveness of **on-train sanders** was examined, and these were found to give a marked reduction in delay. This is believed to be due to a combination of their direct adhesion-improving effect, and the additional confidence they give train drivers to drive more 'sharply'.

Future strategy

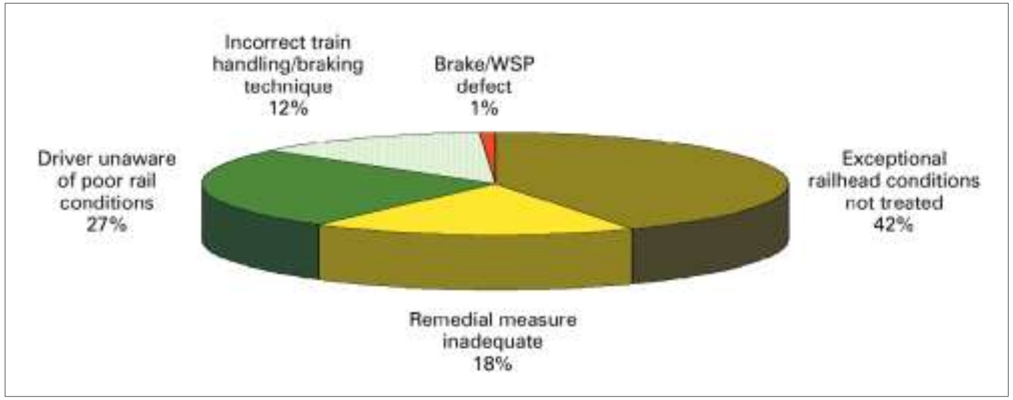
Nothing from the 2003 NADIR study suggested that the recommended strategy in 1999 was in any way deficient and the following recommendations were still considered valid:

- Standardise and implement best practice defensive driving and communications measures.
- Fit sanders for braking and traction to all disc-braked stock used on services susceptible to adhesion delays.
- Design, cost, evaluate and implement a full vegetation management programme targeted at grade 5 locations with significant levels of delay-prone traffic. However, this does not mean that other lower graded sites should not be addressed but is a means of prioritising.
- Continue the water jetting and Sandite programme.

A9.3 Adhesion related incident database

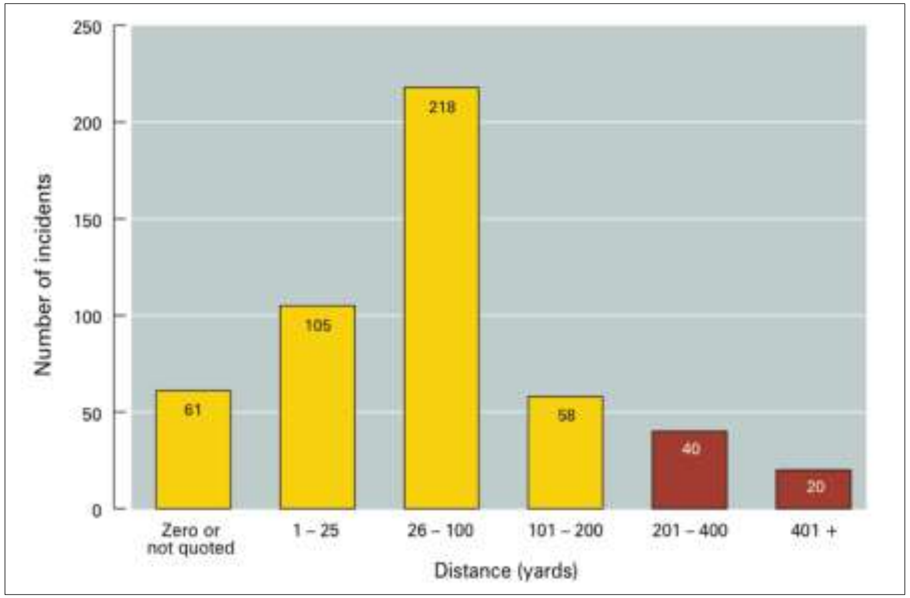
The following data is an analysis of the Adhesion Related Incident Questionnaires submitted by train operators to AWG between 1995 and 2000. Over 1000 datasets are included in this analysis. Although the data is now over 13 years old, it is still considered to be valid. The questionnaire concentrates on safety related incidents therefore no performance related analysis is included. It should be noted that specific datasets are not normalised against the total population, e.g. the proportion of drivers being Specially Monitored suffering an incident is not normalised against total population of drivers as a whole or who are in the Specially Monitored Driver category. Similarly, the numbers of traction units suffering an adhesion related incident are not normalised by mileage operated.

- Types of incident – platform overruns accounted for the greatest number of reported incidents (85%) with SPADs and other types each resulting in 8% each (figures rounded up).
- Causes of incidents – the following pie-chart breaks down the five basic causes for the incidents quoted (note that in some cases more than one cause was considered relevant for a particular incident).



Failure to treat exceptional railhead conditions is the most significant immediate cause of adhesion incidents. Over a quarter of incidents are associated with the driver being unaware of the exceptional conditions (this is where the site is not published as a high risk site and no action has been taken to warn the driver that exceptional railhead conditions exist). Inadequate remedial measures (i.e. the site has been Sandited but not effectively) account for just under 20% and incorrect braking technique for 12% of incidents.

- Overrun distances – the chart below categorises the reported length of overrun.



60 incidents (12%) were in excess of the 'normal' signal overlap distance of 200 yards. These 60 cases can be broken down as follows:

- 7 SPADs and 53 platform overruns;
- 15 incidents (25%) where Sandite had been applied;
- in 10 cases (17%), the time after Sanditing has been provided of which 8 exceed 5 hours;
- 25 cases (42%) involved leaf contamination;
- 20 cases (33%) involved a driver with 5 years or less driving experience.

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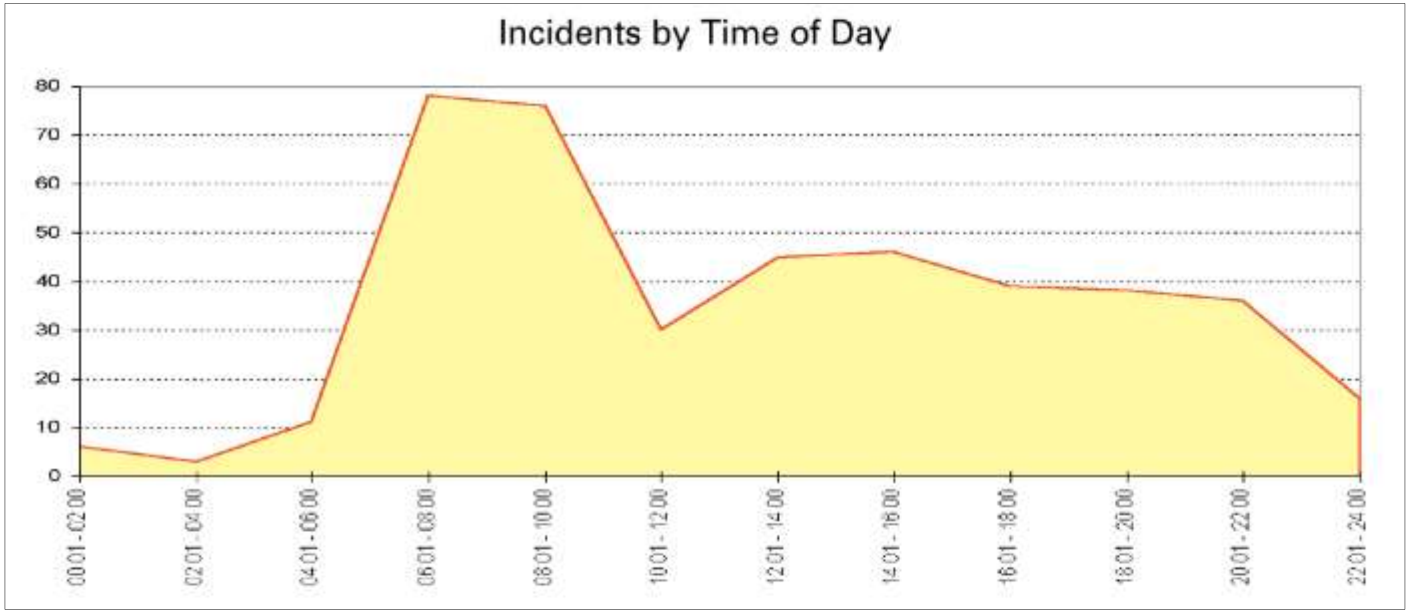
- Time of day – the graph below shows the incidents by time of day. It should be noted that the data has not been 'normalised' i.e. it does not take into account how many trains are usually in service at the various times of the day. The incidents are predominantly in the morning peak, but this is as could be expected because:
  - more trains operate during this period, and
  - it is often when rail conditions are at their worst with dampness on the railhead or dew to activate leaf contamination.



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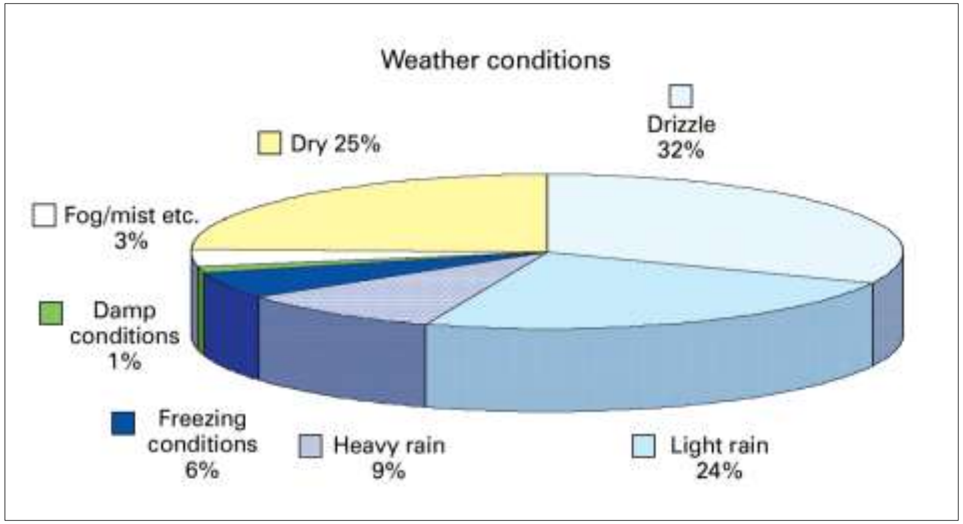
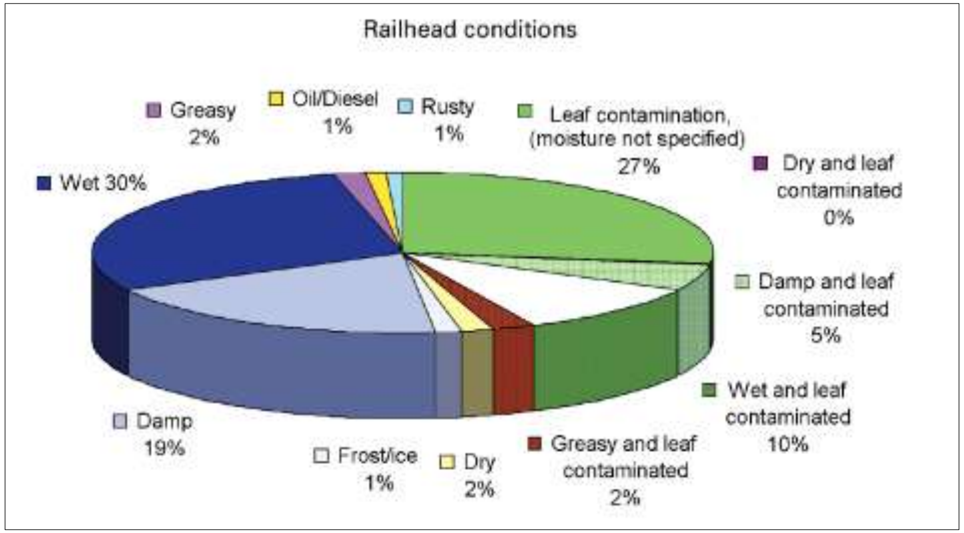
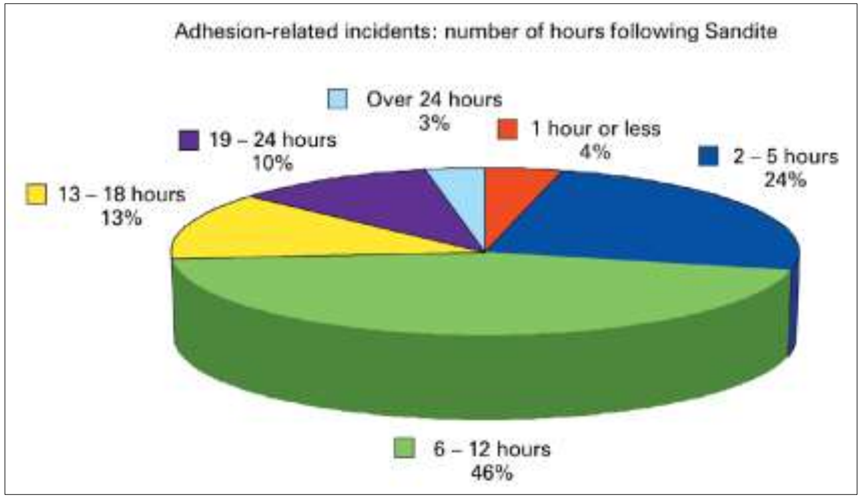
- Weather – the adjacent pie-chart identifies the weather conditions reported for each incident. A high proportion of incidents (60%) occurred in drizzle, dampness, light rain or fog / mist.



- Railhead conditions – the following pie chart shows the stated railhead conditions for the incidents in question. **Just under half of all incidents (44%) involve leaf contamination but it should be noted that nearly half of the incidents involve wet or damp rail conditions without leaf contamination (49%).**



- Sandite application – 86% of reported incidents were within the traditional Sandite season of October to mid-December. Of these, 44% were identified as known high risk sites by being published in the Sectional Appendix. Only 42% of those occurring at published high risk sites had been Sandited.
  In only 22% of the cases where Sanditing had taken place at a published high risk site was the Sandite laid within five hours of the incident occurring. This suggests that the Sandite was not completely effective at the remaining 78% of incident sites. It also suggests that many high risk sites were not Sandited when perhaps they should have been.
  Of the 28% of all incidents where Sandite had been applied at the incident site, the time since Sandite application is shown adjacent.



  The proportion of incidents occurring on Sandited sites where the Sandite had been laid in excess of five hours is 72%. This suggests that a significant number of incidents occurring on Sandited sites are on sites where the Sandite was no longer effective.
- Vegetation clearance – 82% of incidents occurred at sites where vegetation clearance had **not** been undertaken. This confirms that where vegetation management has been undertaken, this is an effective control measure. Of the 18% of incidents at sites where vegetation management had been done – which would be expected to be the 'worst' sites – 42% of these involved leaf contamination.

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- Sectional Appendix high risk low adhesion sites – 42% of all incidents occurred at identified high risk low adhesion sites. Of the remaining 58% of incidents there is a record of the driver being advised of the conditions beforehand in only 4% of these, a very low number. This means that out of the total of over 1000 incidents, the driver had **not** been made aware of the exceptional conditions (either by published information or other advice, e.g. train radio) in 59% of incidents.
- Traction issues – specific traction types have not been included as the data is heavily biased against those traction types used by train operators who have submitted the most forms. In broad terms, 55% of incidents involved EMUs, 42% DMUs, 1.4% HSTs or push-pull sets and 1.0% involved locomotives.
- Brake types – 79% of incidents involved disc-braked rolling stock and 21% involved tread-braked stock. To assist in normalising the brake type figures, the split of brake type between current multiple unit classes equates to around 60% disc and 40% tread brakes. Therefore, it can be seen that disc-braked multiple units are more likely to be involved in adhesion related incidents than tread-braked units.
- Train length – 57% of incidents involved one, two or three-car trains, and 84% involved trains with four or less vehicles.
- Driver experience and training:
  - a high proportion of incidents involved drivers with five years' experience or less. 14.5% of incidents were identified as being attributable, either in whole or part, to incorrect driving / braking technique;
  - the driver had been advised of low adhesion at the location in 41% of cases. This advice had been either via the published details in the Sectional Appendix or by other means such as the train radio, e.g. GSM-R;
  - 23% of incidents involved drivers under the Specially Monitored Driver (SMD) system;
  - in 85% of incidents the driver had received a low adhesion briefing.

A9.4 Autumn 2005 investigation

The autumn of 2005 was not a ‘typical’ autumn, it brought with it an unusual weather pattern, lasting through to late December in the south of the country. Unusually there were also about three peaks of leaf fall rather than the traditional single peak. However, that alone was not considered responsible for the significant increase in key safety indicators in 2005 (427) compared to 2004 (220) and 2003 (331). AWG facilitated a review of Autumn 2005 to determine the causes of the worsened performance.

Eight train operators took part in the review, six of whom had suffered the most problems and two who had shown good performance (to act as a control measure). In addition the review team had had discussions with Network Rail HQ and Routes personnel, ATOC Engineering and Operations and RAIB; who also conducted a review of autumn 2005. Network Rail conducted six-sigma analysis on data, predominantly from incidents in Scotland.

- Weather and leaf fall factors – ADAS analysed 2005 and compared this against 2003 and 2004. This revealed that 2005 was unusual as there were several peaks of high risk days spread over a much longer time period compared to previous years. This equated to an increased seasonal risk in 2005, concentrated in the months of November and December. Additionally, frosts in mid-November added to this by creating an extended season.
- Signals Passed at Danger – fourteen SPADs were initially attributed to poor railhead conditions but, after investigation, five were not attributed to poor adhesion. Significant overrun distances were encountered in SPADs at Lewes and Esher, and significant issues emerged from the remaining seven investigations:
  - residual railhead contamination after the passage of water jetting train;
  - deterioration of railhead conditions after heavy rain but with no evidence of contamination;
  - contamination of the railhead following the late oak leaf fall;
  - the possibility of the WSP of the Class 170s operating at less than optimal efficiency;
  - defects in the process for rail swab tests, and no process for wheel swab tests.

  The SPAD at Esher involving a modern Siemens Desiro train, saw an exceptionally low level of adhesion and was on an untreated section of line. The WSP, dynamic brake and sander systems performed as designed, but the effectiveness of the sander was limited by a cut-off speed of 30kmh and by the need for a greater than 75% brake application before it would trigger. Subsequent tests by SWT and the train builder Siemens established:

- sanding significantly improved adhesion and reduces stopping distances;
- sanding in lower brake steps and down to lower speeds showed further benefits;
- sand was not deflected from the wheel rail interface by aerodynamic effects.

The SPAD at Lewes involving a modern Bombardier Electrostar train, also saw exceptionally low level of adhesion. The underlying causes were identified as:

- a possible change in rail conditions due to rainfall;
- a failure by Network Rail to manage the effects of leaf fall contamination on the railhead;
- a possible failure by Southern Railway to fully appreciate and understand the operation of the WSP and sanding equipment – although both had been found to be working correctly.

The investigation also identified the absence of a system for monitoring wheel contamination.
A subsequent analysis conducted by Southern Railway established:

- an exceptionally low level of adhesion some nine hours after treatment;
- the WSP, dynamic brake and sander systems performed as designed;
- the sander had been effective in increasing the wheel / rail adhesion;
- the effectiveness of the sander was severely limited by a restriction to 10 seconds operation;
- controlled wheel slip had increased the available adhesion down the train by progressively cleaning and drying the railhead;
- the initial use of brake Step-1 had not allowed the sander to operate.

- Station overruns:
  - no standard procedures existed for post-incident investigations;
  - train operator investigations did not involve Network Rail and vice versa, therefore no joint determination of cause;
  - train operator investigations did not routinely include train engineering expertise;
  - the information available was insufficient for any detailed analysis of root causes.
- Six-sigma analysis –conducted by Network Rail's experts from Scotland, this identified:
  - there is only a weak correlation between high risk days and delays or incidents, suggesting that forecasting factors and the response to them need to improve;
  - delays and incidents fell dramatically when railhead treatment was switched from water jetting only to water jetting plus Sanditing;
  - there is a need to improve measurement of autumn factors and outputs;
  - national / route level data cannot be used to infer autumn performance.

Headline findings

The main findings from the 2005 autumn investigation were grouped into five headings (see below), but the headline findings were:

- the pattern of weather and leaf fall led to an increased risk in autumn 2005;
- the most effective rail cleaning treatments were not consistently adopted;
- sanding systems did not always exploit the scope allowable within the group standard;
- the use of Step-1 braking in poor adhesion does not allow the sander to operate on the majority of trains;
- driving policy risks creating a different ethos for approaching stations compared with stop signals.

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Infrastructure findings

- comparative tests concluded that the best method of railhead treatment was a combination of water jetting and Sandite;
- no evidence was seen of the decision making process leading to widespread use of water jetting alone;
- advantages of water jetting were stated to be: increased application speed and, reduced risk of WSTCF;
- the decision on method of treatment to be adopted was left to Network Rail route managers;
- some incidents occurred at untreated sites or so long after treatment that it would have ceased to be effective;
- train operators rated vegetation management between excellent and poor;
- known low adhesion sites were not always treated;
- the Sectional Appendix low adhesion sites reported to be largely historically based.

Train design findings

- investigations by Southern Railway and SWT confirm effectiveness of sand in reducing stopping distances;
- limitations on the sander operation of new EMUs severely reduced sander effectiveness;
- trains without sanders performed poorly – e.g. Class 357/0 on C2C, 14X on Northern and 314 in Scotland;
- WSP performed as designed with the possible exception of the Class 170;
- the dynamic brake performed as designed, allowing the WSP and sander systems to operate correctly.

Operational findings

- the use of Step-1 braking in poor adhesion does not allow the sander to operate on the majority of trains;
- 83% of station overruns involved short trains;
- there was no standard procedure for investigations following a station overrun;
- when dynamic braking is in use, drivers will experience wheel slide more frequently, creating an impression that new trains slide more easily than older stock in poor adhesion conditions.

Driving policy

- ATOC Guidance Note GN007 “Defensive Driving Techniques” states that any reference to treating the approach to a station as the same as running up to a stop signal should be avoided;
- train operators generally follow this guidance, risking creation of a different ethos for approaching stations compared with stop signals;
- GN007 is ambiguous in advocating avoidance of an aggressive approach to braking for through stations, whilst at the same time advocating full use of braking capabilities – GN007 has now been withdrawn;
- driving policies do not generally provide guidance on the characteristics of specific train types in poor adhesion conditions, or of single unit trains.

General findings

- risk predictions did not always correlate with actual poor adhesion days;
- incidents of trains slipping where no contamination was visible that were swab tested has not revealed the nature of any residual contamination;
- swab tests do not indicate anything about the levels of adhesion prevalent at the time.

A9.5 Autumn measurement trials 2006

In 2006, Network Rail commissioned extensive testing in controlled conditions off the network to understand the adhesion levels experienced after various railhead treatments. Following this, in collaboration with Southern, the opportunity was provided to investigate current adhesion performance in autumn conditions on the live network. This work also allowed the investigation of wheel contamination as well as railhead contamination. The following is a summary of a report prepared for Network Rail by Ove ARUP and Partners.

Network Rail's Six Sigma Black Belt specialists devised the process used for the autumn 2006 measurement programme, in conjunction with inputs from Network Rail's operational staff and general industry consultation. The programme was designed to examine the factors influencing wheel slip, the coefficient of friction and contamination thickness. The objectives of the tests were to:

- carry out initial screening experimentation during the autumn period under 'live' railway conditions;
- determine the significant factors and interactions with respect to maximising train braking performance such that they can be carried forward into more detailed future experimentation;
- provide lessons learnt from this initial study which can be used in determining the strategy for autumn 2007.

The initial phase of the experiment included factors which were controlled, fixed or monitored, and two states were used for the controlled factors: a high and a low status. The factors considered are shown in the table below.

Factors which were controlled and varied	Factors which were controlled and fixed	Factors which we uncontrolled, treated as noise and measured
• Direction of travel • Train treatment longevity • Train length • Leaf management / source • Speed • Treatment type • Train sand	• Location • Train type • Gradient • Braking procedure	• Relative humidity • Air temperature • Wind speed • Coefficient of friction on railhead • Contamination thickness on wheel • Contamination thickness on railhead • Railhead dampness • Driver response • Train unit

The data collection process involved a series of controlled brake tests with a service train, serving as the primary measure of adhesion experienced by the train. The tests were conducted in autumn conditions on the operational railway. Southern provided Class 377 stock for the testing, driven by Southern's experienced test drivers. The testing was integrated with the delivery of existing autumn treatment diagrams to ensure that it did not disrupt normal operational treatments.

The railhead friction was measured using a Salient Systems tribometer before and after the brake test. Contamination thickness measurements were taken with an eddy current meter. Spot measurements of air temperature, humidity and wind speed were taken as well as subjective observations of whether it was raining. Swabs of the railhead were taken before and after the brake tests. A weather station was installed at the site to take continuous measurements over the whole period of the tests. The deceleration of the train through the test site was measured by an accelerometer, by a GPS system and by the On-Train Data Recorder. The thickness of contamination on the accessible wheels was also measured.

Network Rail's Six Sigma team undertook a detailed statistical analysis of the data gathered and derived the following conclusions:

- the best overall braking model is achieved when leaf count is minimised; railhead coefficient of friction is maximised; uphill gradient; soon after an MPV treatment run; and the treatment is water jetting followed by Sanditing;
- the worst overall braking model is achieved when leaf count is maximised; railhead coefficient of friction is minimised; downhill gradient; long after the Rail Head Treatment Train treatment; and railhead treatment is water jetting only;

The analysis generated recommendations for future experimentation to focus on:

- treatment longevity – understand and obtain optimal duration between treatments for best braking performance;
- gradient and treatment type – understand the effect on braking performance by varying actual gradient 'values' and treatment types;
- speed and treatment longevity – understand the effect on braking performance on higher speed lines by varying the time between treatment runs;
- understand the factors that cause variability on the coefficient of friction on the railhead;
- test the validity of the findings on factors which were controlled but not varied e.g. brake type, WSP type etc.

The analysis also resulted in recommendations for the autumn 2007 strategy:

- gradient to be included as a risk factor when determining the strategy for autumn; locations on downhill gradients are to be considered higher risk than those on uphill gradients;
- Rail Head Treatment Train frequency to be included as a risk factor when determining the strategy for autumn; high frequency service lines (high axle passes) with long duration between treatment passes are to be considered a higher risk;
- locations that are tree lined are to be included as a risk factor when determining higher risk areas for autumn.

In addition to the analysis conducted by Network Rail, Arup analysed the data to gather additional information and concluded the following statistically significant findings:

- There is strong statistical evidence that shows that water jetting and Sandite results in higher decelerations than water jetting alone. Water jetting and Sandite also results in more consistent decelerations than water jetting alone.
- There is statistical evidence to suggest that trains that braked on treated track had higher levels of deceleration than trains which braked on untreated track.
- There is statistical evidence to show that the mean deceleration value for trains braking approximately 200 axle passes after any type of treatment, is no different to the mean deceleration value for trains braking on untreated track.
- There is statistical evidence to suggest that, during these trials, trains braking on track treated with water jetting and Sandite are not affected by the available leaf source. There is some evidence to suggest that trains braking on track treated with water jetting alone may experience reduced decelerations as the available leaf source increases. The dataset is small for these cases and there is insufficient data to confirm the findings.
- There is a statistically significant relationship between the presence of contamination on the rails and the presence of contamination on the wheels. There is no evidence of a relationship between the thickness of contamination on the rail and the thickness of contamination on the wheel.
- When there is contamination on the wheels and no sand or Sandite present, then there is statistical evidence to show that the deceleration of the train is linked to the contamination thickness on the wheels.
- There were statistically significant but weak relationships between contamination present on the rail, minimum temperature and maximum wind speed. The same relationships exist for contamination present on the wheel but are weaker.
- There was a strong statistically significant relationship between mean wind speed over the previous 24 hours and the presence of contamination on the rail. The same relationship exists for contamination present on the wheel but is weaker.
- When contamination was found during the testing it was most likely to be present on both the wheels and rails. In the event that contamination was present on only one side of the wheel / rail interface, the results show that

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there is an equal occurrence of wheel only contamination and rail only contamination. Therefore, the lack of contamination on the railhead is not conclusive evidence that the wheel / rail interface was free from contamination.

- There is a statistically significant relationship between the ADAS forecast and presence of contamination on the rail. For the test site location there were only green and yellow ADAS forecasts during the testing period. The data shows that on a yellow day contamination was present on the rail more often.
- There is a weak statistical relationship between the tribometer adhesion measurements and train deceleration. The relationship only accounts for a low percentage of the variation seen in the results.

Arup made the following recommendations:

- **Wheel contamination should be considered as a significant factor in the braking performance of trains.** The study found that wheel contamination is just as likely to be present as rail contamination, and the presence of wheel contamination is linked to the presence of rail contamination.
- **Water jetting and Sandite treatment provides the best method for improving adhesion in autumn conditions and should be used where possible.**

A9.6 Review of autumn 2010 by John Curley and David Rayner

The National Task Force (NTF) commissioned a review into the causes of a significant deterioration in autumn KPIs and operational performance in autumn 2010. The remit was to determine if this was a result of:

- inadequate planning by the industry;
- any shortfall in the effectiveness of the railhead treatment regime provided by Network Rail;
- the adequacy of preparation of rolling stock;
- or other factors.

In addition, the review sought to establish the extent to which the then existing portfolio of measures was adequate to deliver the increasing levels of performance required of the industry.

Taking a medium to long-term view based upon available meteorological and leaf fall data, autumn 2010 was at the challenging end of the spectrum of 'normal autumns'. July and August 2010 were warm and wet and provided excellent growing conditions for the leaf canopy. September and much of October were benign without either hot dry weather or frost and strong winds, with the result that the heavy leaf canopy was substantially retained on the trees until late October. Whilst timing varied across the country, a consistent pattern in the last few days of October saw a series of significant frosts followed by several days of strong winds and rainfall. This led to a significant and rapid period of leaf-fall concentrated in the first two weeks of November, during which period the majority of the autumn KPIs and delays were incurred. Autumn was therefore concentrated into a short period of time and this could be observed by the rapid ramp-up and ramp-down of autumn category delay minutes incurred for 2010. By comparison, the autumn of 2009 was particularly benign with no significant weather events and a long progressive period of leaf-fall.

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Autumn KPIs

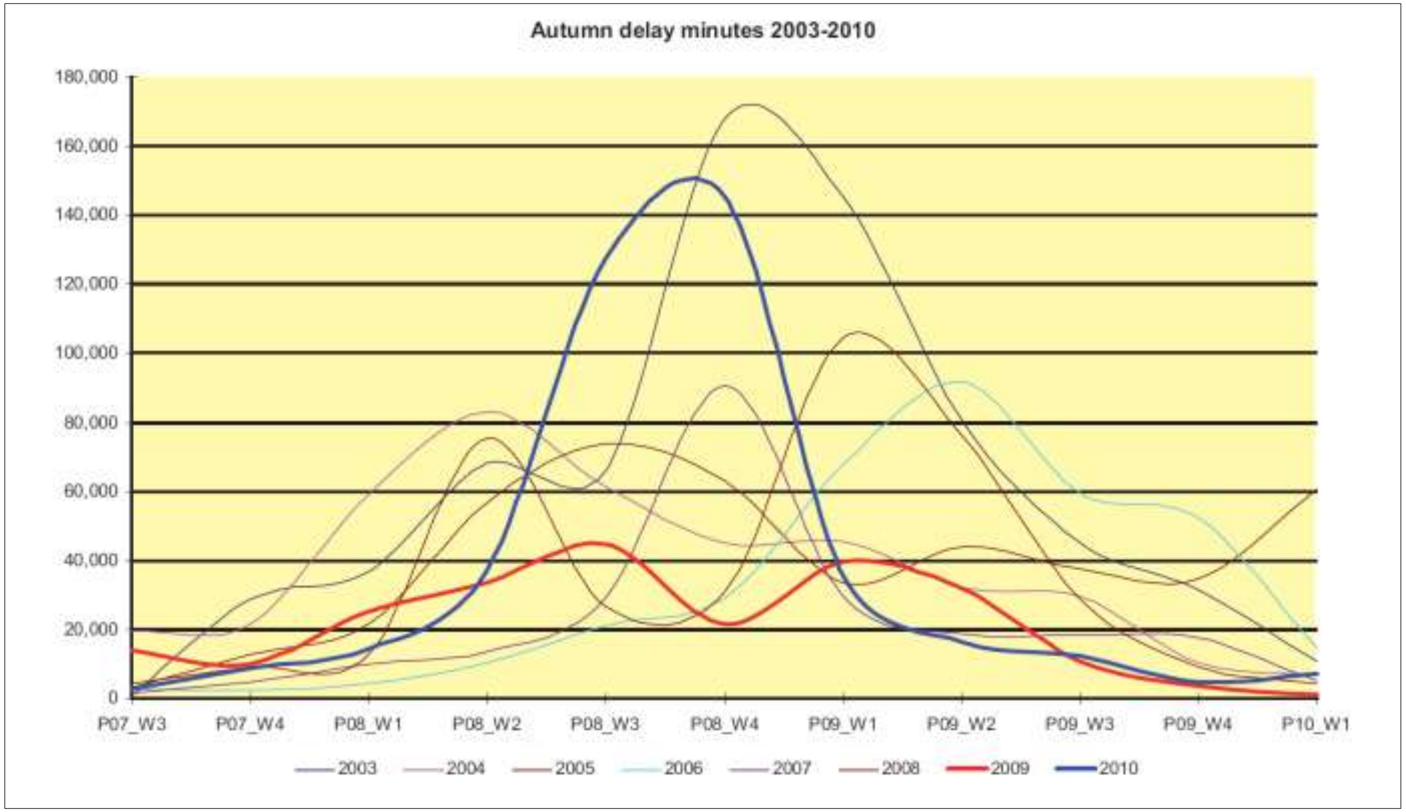
The review found that the historic trends in autumn KPIs has been mixed, but 2010 was clearly worse than 2009 for all indicators. That said, normalisation of station overruns was deemed a future need and SPADs are statistically variable each year due to low numbers. However, WSTCFs were most pronouncedly higher. From a low point of 50 in 2007 there had been an upward trend, the 2010 level of 133 was the highest in the recorded data series.

The review found that the data required to understand more fully why this was happening is held in a number of disparate systems, which as far as the review had been able to ascertain were neither interlinked nor reconciled. This made evaluating the overall system risk very difficult, and again, as far as the review had been able to ascertain, this was not something which had been undertaken.

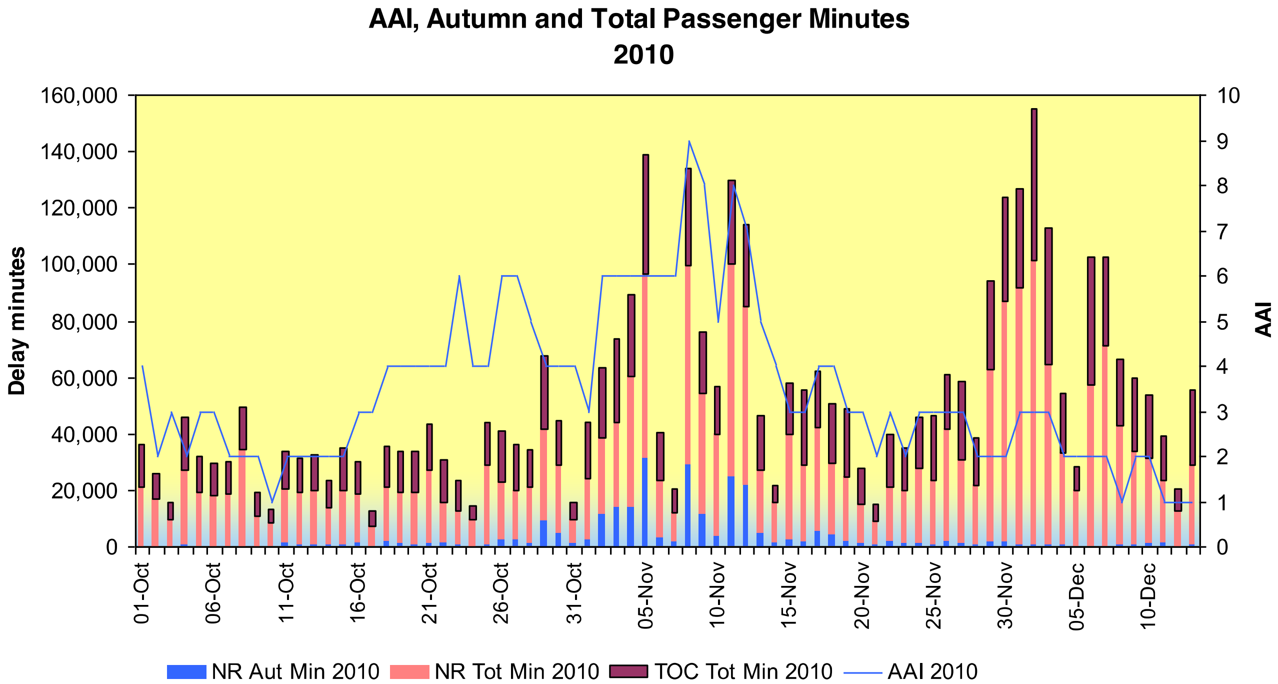
The data confirmed the picture of increasing numbers of WSTCF over recent years to 2010. Until recently WSTCF were only known about if they were either observed by the signaller or resulted in the interlocking registering their occurrence. In many cases WSTCF are transient and can potentially go unobserved. Recent implementation of monitoring equipment and the fitment of data-loggers to signalling systems is leading to a growing number of WSTCF which were previously likely to have not been observed now being recorded. Conversely, the progressive replacement of track circuits by axle counters is expected to contribute to risk reduction.

Train Delays

Total industry delays incurred during the autumn period have declined over time as a result of both a general industry improvement in performance, and the specific actions focussed on autumn. It can be seen from the graph below, that 2010 had one of the most concentrated autumn periods for autumn delay categories in the last eight years. 2010 was worse in terms of passenger delay minutes than any year since 2006. However, it showed a result significantly better than in 2003, which was the most recent year with a similar distribution of leaf fall and autumn effect.



Using the seasonal weather predictive model output (the Autumn Adhesion Index (AAI)), the correlation between the forecast AAI and the occurrence of identified autumn delay minutes and total industry delay minutes on a daily basis was made. The graph below shows a good correlation between the forecast AAI, autumn category delay minutes, and total industry delay minutes. It is based upon a daily average AAI from the two forecasts for each of the 22 areas. This was also looked at for correlation by Network Rail Route, and was found to be even stronger.



Note: From 29 November heavy snow fall was experienced across the network

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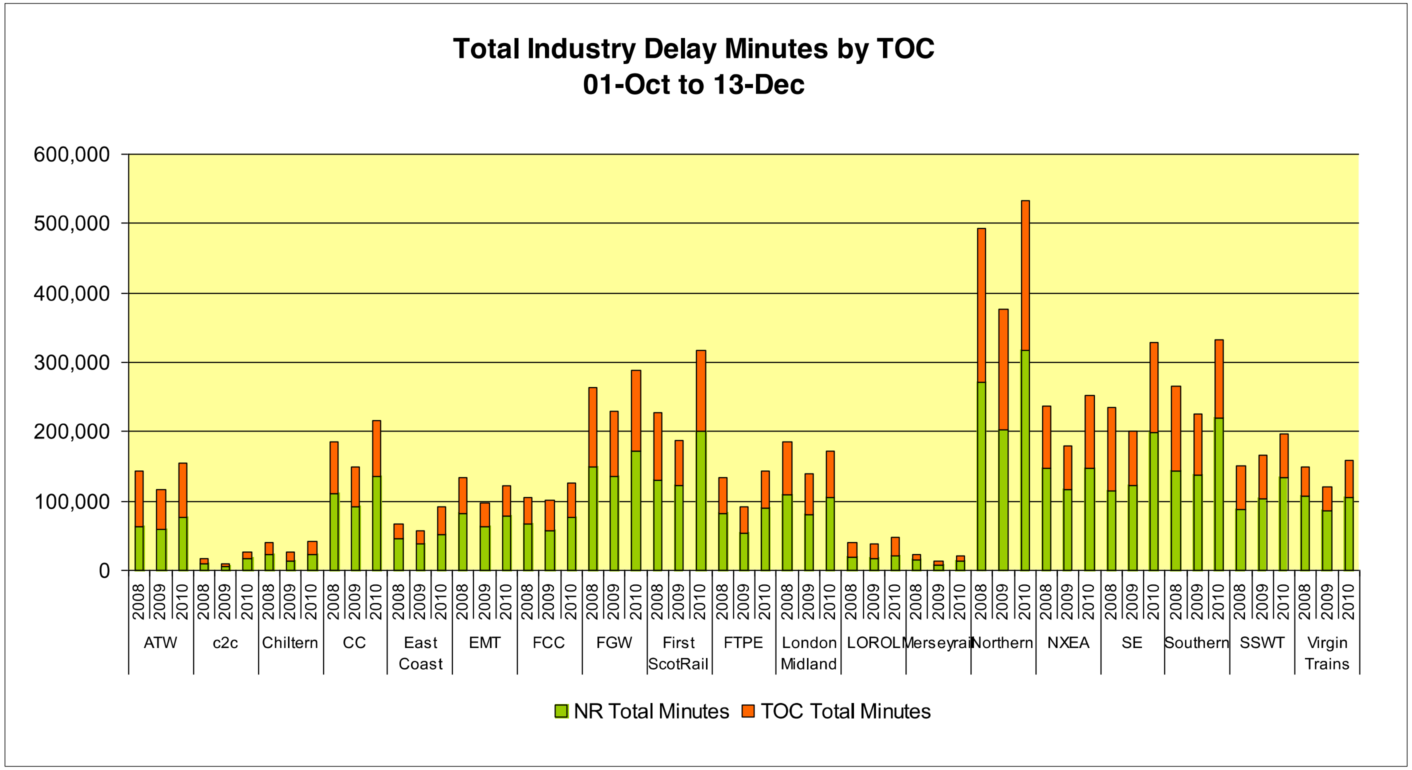
Managing Low Adhesion

The graph below illustrates the total industry delay minutes for franchised passenger train operators, over the previous three years. The results for 2010 were slightly worsened by the early onset of the severe winter weather. All operators suffered significant disruption over the period. However, the worst deterioration compared with the previous two years was experienced by Northern Rail, Southern, and Southeastern.



The major issue for freight operators was their trains stalling on rising gradients due to inadequate grip for traction. There was a perception that the incidence of these events was increasing as a result of the progressive move to heavier trailing loads. The emphasis when developing autumn treatment programmes has been around establishing the most favourable conditions for trains to stop. However, after delivering safety, the second priority of the

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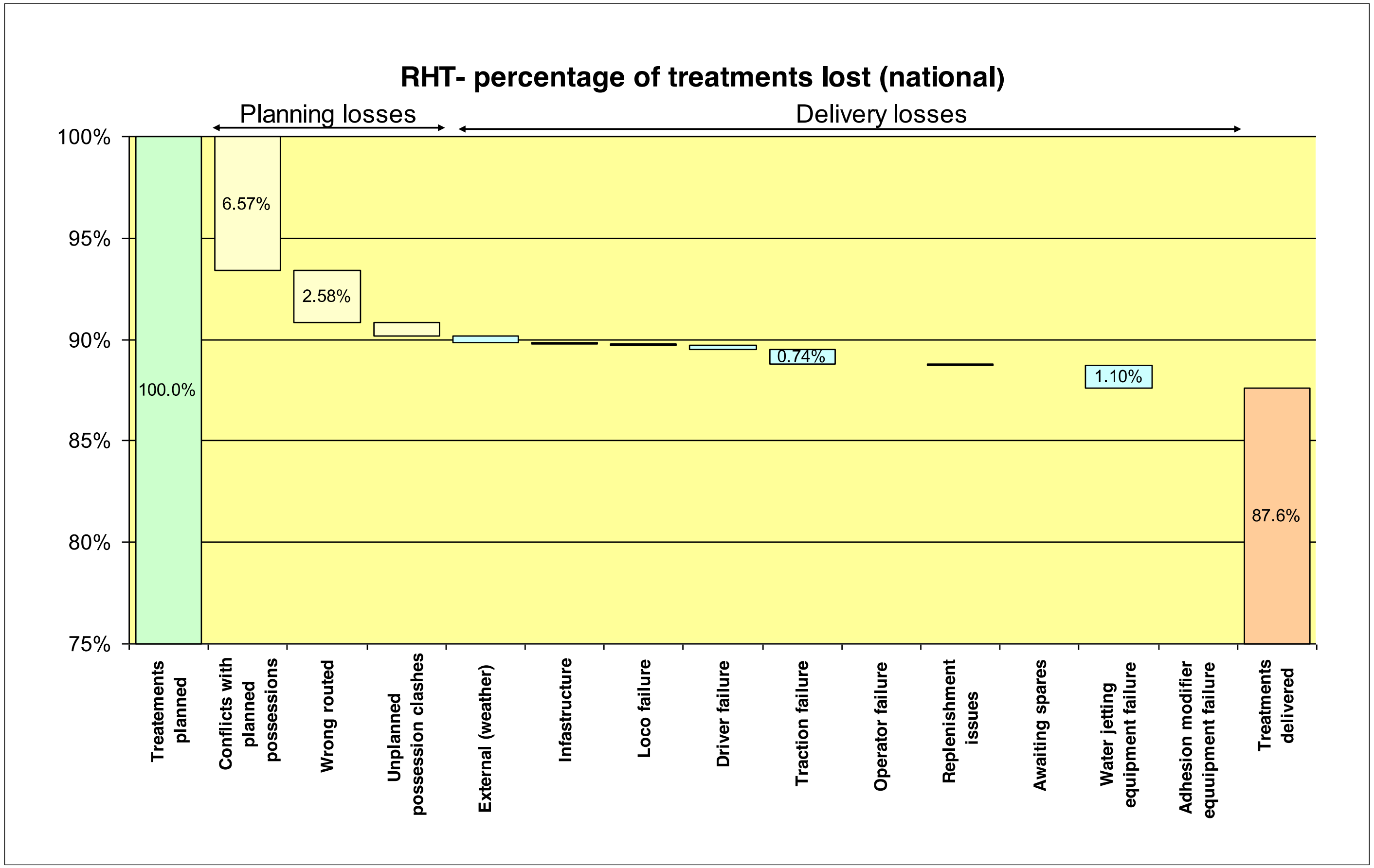
programme should be to protect performance. **Sites identified as risks for freight trains stalling should be risk assessed and incorporated, as necessary, into the railhead treatment programme, with TGAs fitted if appropriate. Network Rail Routes, in conjunction with freight operators and in consultation with passenger operators, need to identify locations where the delivery of 'clear run' conditions would reduce the risk of freight trains stalling on rising gradients.** It was also deemed incumbent on the freight operators to ensure that sanding equipment fitted operated correctly and was fully stocked, and to consider, when the conditions are expected to be particularly poor, reducing the trailing load or increasing the motive traction.

Railhead Treatment Programme

The scale of the railhead treatment programme had grown incrementally over time. In 2010 the industry deployed 32 MPVs and 22 locomotive hauled trains (RHTT). This required the provision of 52 x Class 66 locomotives, the necessary train crew resource, plus machine operators for each consist. During the 2010 programme the fleet covered in excess of 800,000 miles covering around 3500 circuits.

The standard capability offered by both the MPV and RHTT fleets for 2010 was to water jet at 1500 bar and apply Traction Gel 60 (TG60) with a maximum operational speed of 60mph. The detailed specification for treatment sites was derived in discussion between the Routes and train operators. In many cases historic knowledge of problem sites, or consideration of pathing or traffic density, led to the treatment being carried out at lower than the maximum speed (e.g. 30-40mph). On the majority of Routes, the 2010 programme struck an effective balance between the opportunities presented by 60mph treatment and the effective treatment of the more difficult sites. One Route delivered water-jetting only, but this was not in line with established best practice. In Kent and Sussex Routes the desire to achieve operational and financial efficiency tipped the balance heavily towards 60mph operation and inter-working between the Routes leading to lower reliability and less effective treatment of problem sites.

87.6% of the sites identified in the base plan were treated nationally as shown in the graph below. The best Route achieved 95.7% and the least effective Route achieved 79.2%. The majority of losses occurred in the planning phase, conversely sites lost in delivery accounted for just 2.55% nationally. **A key element in robust planning is optimising the engineering possessions to enable the proposed circuits to be delivered without conflict with engineering work. This should take place in the early stages of the planning cycle.**



On some Routes the desire to exploit the opportunities provided by TG60 and 60mph water jetting led to late changes to the circuits and revised bids being submitted up until March 2010. This required the Network Rail Operational Planning team to dedicate additional resource to timing these circuits. Consequently, the finalised timings were not available in some cases until late August 2010, and the ability to optimise against possessions was severely constrained. Late completion of timings constrained the ability of the contractors to plan their final resourcing and logistics effectively.

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Overall, the principal causes of lost delivery were traction failures and failure of water jetting equipment, each of which contributed to a loss around 1% of the base plan by treatment site. The main cause of traction failure was the loss of an MPV for four weeks though fire arising from an accumulation of leaves above the engine; and a series of gearbox failures. The water jetting failures were primarily due to blocked filters and pump failure in the early stages of the programme. This equipment is overhauled annually and the consists reassembled prior to autumn. Prior to 2008, the programme included a 'shake-down' week to familiarise drivers and operators with the equipment and to expose any early faults. The view was then taken that this week was unnecessary and that the first week of the planned programme was generally operated in benign conditions and could be substituted for the 'shake-down' week. However, in 2010, a number of Routes decided to cancel the first week of the programme, leading to untried equipment being deployed in live operation in deteriorating autumn conditions.

In 2010 there was a significant increase in the delays attributable to the railhead treatment programme. On some Routes this represented 30-40% of the Network Rail autumn delay categories. In the overall industry context railhead treatment delays totalled around 100,000 minutes out of an industry total of around 2 million minutes in Periods 7 and 8. Major train service disruption arose from MPV traction failures in key locations at peak times. The impact of these failures was exacerbated by difficulties in assisting failed units, driver unfamiliarity with technical fault finding, and a lack of a clear 'cut and run' policy.

The review found that TGAs were beneficial and that, subject to appropriate maintenance and overhaul arrangements, reliable. Generally, there were robust processes in place to engage train operators in the detailed decisions regarding locations at which these were deployed. **Routes need to ensure that there is a regular review process to identify any reallocation of TGAs required as a result of changes in service pattern or traction type.** However, despite their overall success as an autumn mitigation they require regular replenishment and checks to ensure their correct operation.

Vegetation Management

The management of vegetation is a very high profile issue with train operators. The review received comments from most train operators that in their opinion the level of vegetation management undertaken was insufficient to fully mitigate the effects of autumn. However, in some Routes there was a medium-term to long-term strategy developed with the train operators, and this clarity of purpose helped towards effective delivery (e.g. ease of agreeing possessions). Best practice in this area was observed in Sussex, Anglia and Western Routes.

Network Rail manages lineside vegetation to a particular specification laid out in NR/L2/TRK/5201 "Management of Lineside Vegetation". The review found significant non-compliance with this standard, varying in degree across the Routes. Autumn factors are a key input to designing the vegetation management programme, but there are others, such as signal sighting, which may result in resources being even further stretched. While the review was not able to find a comprehensive dataset, there is strong evidence that the level of activity on vegetation management had declined over recent years.

Notwithstanding the constraint of budgets, Network Rail and its predecessor had cleared a very large number of sites over the last 15 years. Unfortunately, there has been less than rigorous delivery of maintenance activity to prevent re-growth at these sites. It was apparent that the budgetary pressure focused activity on the next site to be cleared at the expense of maintaining the progress already achieved.

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Communication and Control

Evidence from Route reviews illustrated that:

- on the worst autumn days, the normal Control resource was fully deployed in managing incident response and service recovery; and
- those Controls that had retained dedicated autumn control resources were best able to manage and exploit the proactive redeployment and direction of the autumn treatment resource.

However, concern was expressed on several occasions that the contractual process for redeployment could be cumbersome and slow to react. Further, where a Route had a team of individuals who had built up experience over a number of years in the autumn control role, the effectiveness of response was noticeably enhanced; Anglia Route represented best practice in this regard.

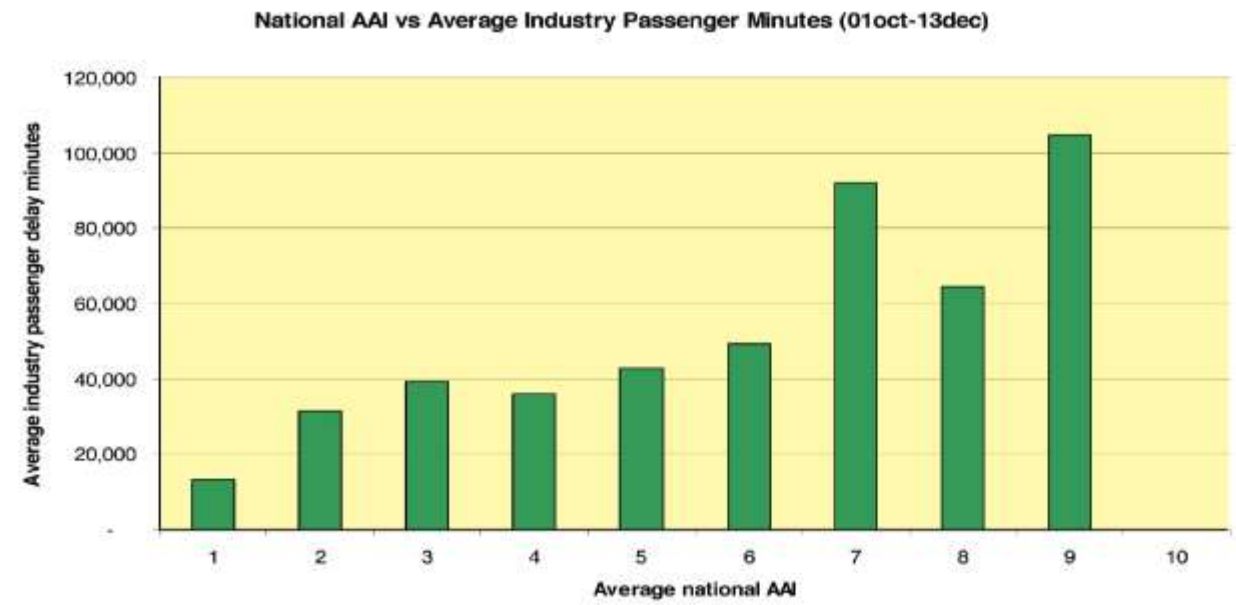
Upon receipt of a report of exceptional railhead conditions trains are stopped at signals, drivers are required to contact the signaller, and cautioned that the conditions on the railhead ahead may be exceptionally poor. This process continues for each subsequent train until the railhead has been examined by Network Rail response staff. The process of stop and cautioning in an area in which it may be difficult to stop is counter-intuitive. The 2010 review pointed out that implementation of GSM-R train radio, which can be used to communicate globally to trains in specific geographical areas, had potential to render this requirement obsolete and it has. Practice now is that, where possible, upon receipt of a report of exceptional railhead conditions, drivers are contacted via GSM-R about the railhead conditions using the caution on the move function.

The ‘30-minute rule’ was an initiative trialled in Kent in 2009 and Scotland in 2010. Where a report of exceptional railhead conditions has been received, and it has not been possible to get a site inspection carried out within 30 minutes, then the next train is instructed to carry out a controlled test stop. If this stop is successful, then normal working is resumed. The trial in Scotland in 2010 was judged to be highly successful by both First ScotRail and Network Rail and has since been added to the Rule Book – GE/RT8000-TW1 “Preparation and movement of trains”.

Whilst the quality and geographic detail of the autumn forecasts is recognised to have improved markedly it is not sufficiently focused to predict the specific conditions that a driver will meet over the course of their shift. The emerging data from the detailed measurement of microclimate carried out during autumn 2010 on Wessex Route, in conjunction with SWT, has underlined that local microclimate can vary considerably over short distances and change rapidly at any one location. The review found uncertainty amongst operators on how daily briefings could best balance the need to alert drivers to days where overall conditions are likely to be poor, without leading to driving practice that may be more defensive than specific local conditions required.

Effectiveness of mitigations

The graphs below show the relationships between performance and the conditions experienced in the autumn of 2010. For each of the days in the autumn period the average AAI from the two forecasts for each of the 22 areas was been calculated. For all of the days at any level of average AAI, the national passenger delay minutes have been averaged.



Note: The apparent inconsistency in the data above for a National AAI of 8 is a statistical anomaly due to a very small dataset

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The above graph shows a progressive worsening in delay as the AAI increases from one to six, beyond this point delay increases exponentially. This relates to what are referred to as 'red days' and 'black days'. The progressive increase in the autumn effect erodes the operational robustness of the network, trains are losing time accelerating and braking, junction margins are eroded, and the whole network becomes more fragile. Once AAI passes six, how poor a given day is depends on the level of incidents. Even incidents which would normally have only a small delay impact can take on major significance when network robustness has been lost. In these conditions perturbation management and service recovery become far more challenging.

The autumn analysis graph below shows the relationship between the level of railhead treatment delivered to the network, the industry delay minutes, the AAI, and a weighted index of autumn KPIs. The graph illustrates that through the core autumn period, Network Rail generally deploys all of its available capability, and this manages to mitigate the conditions up to an AAI of around six. However, there is no additional resource available to deploy if conditions worsen further.

This analysis helps to explain the difference between 2009 and 2010 performance. In 2009 the benign conditions facilitated a fairly even leaf fall of around 10% per week for 10 weeks, there would have been very few days where the AAI would have exceeded six. This compares to the sudden and sharp fall in 2010, with approximately 60% of the leaf fall occurring over two weeks, which contained a number of days which exceeded an AAI of six.

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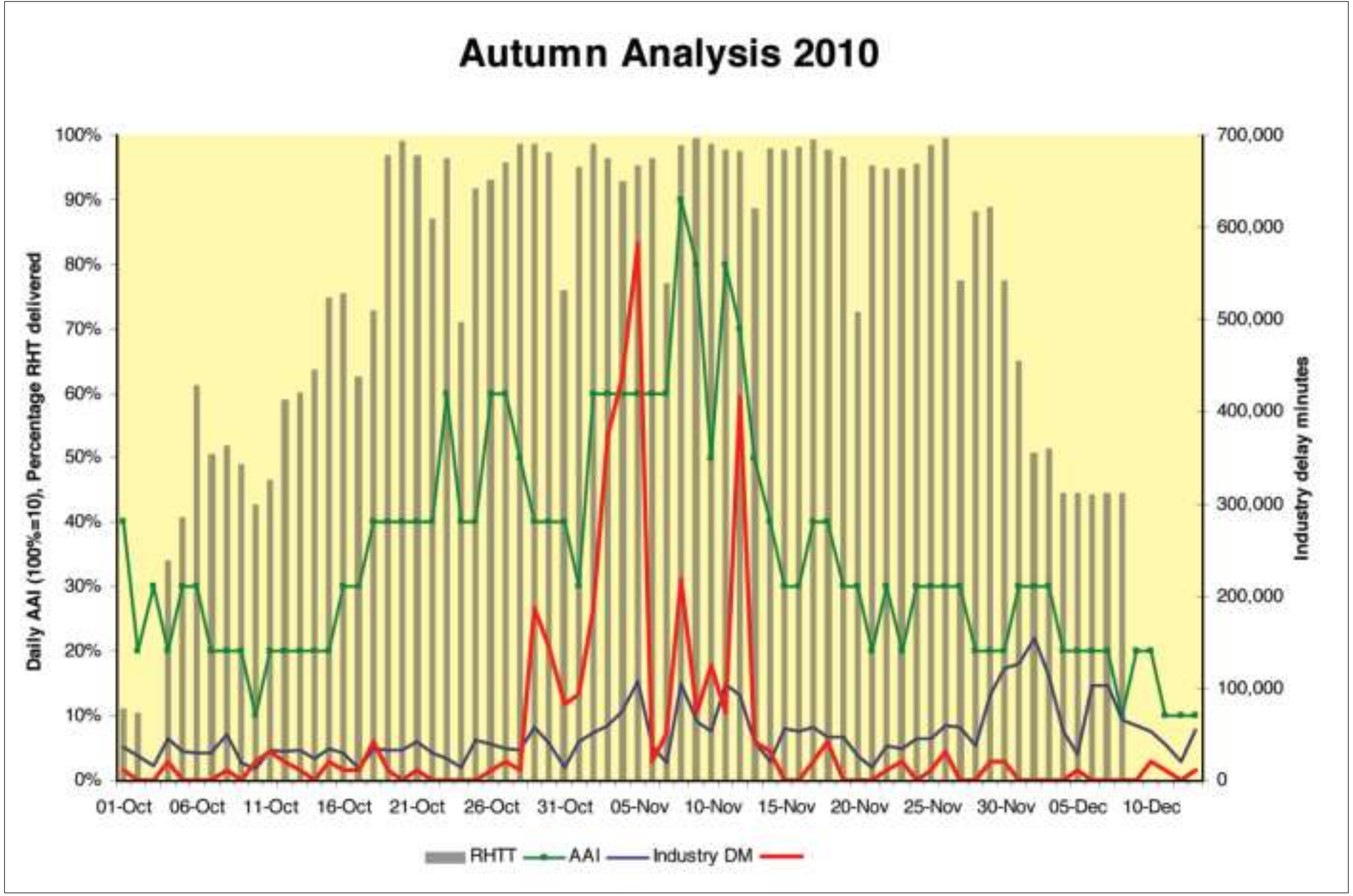


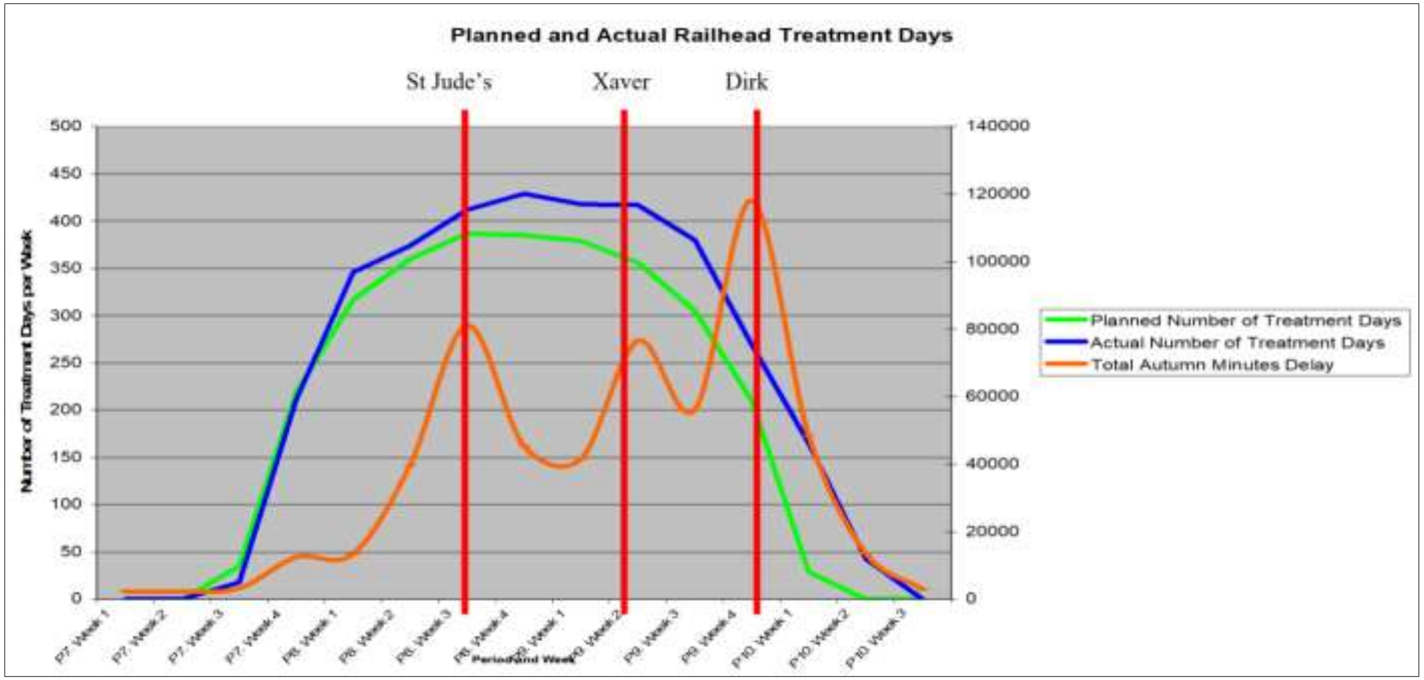
A9.7 Review of autumn 2013 by John Curley and Claire Volding

In November 2014, National Task Force (NTF) agreed that an independent review should be commissioned to address the materially higher autumn safety KPIs and delay minutes of 2013. The review used semi-structured interviews with key individuals and teams across the Industry.

Conclusions

- Leaf-fall and 'Wet Rail' – Network Rail's seasonal management processes defined the autumn season as starting on the 1 October and finishing on the 13 December, however 2013 was characterised by a number of storms which significantly impacted on autumn performance and KPIs that fell outside this calendar. Whilst the impact of leaf-fall was very significant during most of the autumn period, poor adhesion arising from 'wet rail' became a very significant factor in the poor performance. Taken together with the extended leaf-fall pattern this meant that the autumn effects were evident for two to three weeks later than has been normal in recent years.
- Weather forecasting, Autumn Adhesion Index (AAI) and 'black' days – whilst the AAI includes an algorithm reflecting leaf-fall to date this seems to have inadequately reflected the build-up of fallen leaves prior to the major storms. This caused a number of issues because the storms had a bigger impact due to all the leaves in the area. It also underestimated the impact of the late falling species and the 'wet rail' effect. Extreme Weather Action Teams (EWATs) took place on the storm days in many areas however the consensus from Routes and train operators was that the EWAT process could work well but that this it is dependent on the continuity of personnel in the Seasons Delivery Specialist role which was continuously changing.
- Railhead Treatment Programme Plan:
    - Routes had varying applications of the treatment programme. For example, some used Sandite rather than TG60 and laid at 40mph with some jetting through switches and crossings.
    - One of the main issues across Routes was that the majority of circuits were copies of the previous years with more sites added. There was no risk assessment that took into account all of the factors that should be considered in developing a dynamic risk assessment to target the autumn interventions. The circuits were also not always planned to align with the timetable to prevent adhesion issues for key routes.

- The report also highlighted that due to Network Rail's National Supply Chain (NSC) contractual restraints of the treatment programme, Routes were only able to cancel a specified proportion without penalty. Routes could request the contractor to run additional circuits beyond those specified in the base plan, but the contractor is only obliged to use best endeavours to meet these requests. This caused issues as Routes booked the minimum base circuits and then had issues when trying to extend the treatments as they could not always be resourced and provided.
- The report concluded that the core autumn treatment programme should have been extended by at least an additional two weeks due to the prolonged nature of autumn 2013. It was also recommended that a shakedown week would have been beneficial on all routes.



- Traction Gel Applicators (TGAs) – a wide variance across the network was found in terms of ownership, maintenance and use of TGAs. The report highlighted that there has been limited detailed research into their impact which has left some individuals sceptical of their value.
- Front Line Staff and Controls – many of the Routes used autumn Mobile Operations Managers (MOMs) or leaf-fall teams, however there were varying practices and tools and the major issue identified was that very little was formally recorded.

  Where autumn controls existed, they were often Monday to Friday with limited weekend cover, however a significant number of autumn related incidents can occur at weekends and the impact of extended weekend possessions on the railhead treatment programme can be quite considerable. Train operators endorsed the work of the autumn controls, but felt that on occasions an opportunity was lost to fully communicate to them the detail of what was being delivered.
- Vegetation – vegetation clearance was primary reactive and there was not a national vegetation maintenance programme because it was directly linked to funding that had not been historically consistent, meaning vegetation clearance was far beyond the maintenance stage. Because much of the clearance is done by contractors this specification is often applied in a literal way to the standard resulting in the partial removal of tree canopies. Furthermore, whilst the issues of third party trees and the bird nesting season are real, they are used as excuses for inaction rather than being seen as obstacles to overcome.
- Train drivers – there had been a very significant level of recruitment and training of new drivers and consequently unusually large number of recently qualified drivers experiencing autumn for the first time in 2013. There was inconsistent reporting of conditions of poor adhesion or exceptional railhead conditions by drivers due to subjectivity. It is generally recognised that it is beneficial for drivers experiencing their first autumn to be accompanied by a competence manager or instructor who can guide them in putting particular conditions into the autumn context.

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- Rolling stock:
  - The industry had made very considerable progress in the deployment and operation of sanders to rolling stock since 2010. The vast majority of trains operating in autumn 2013 were fitted with sanders.
  - The increasing focus on fuel efficiency and cost of operation means that there are a number of multiple units that on occasion operate with an engine shut down or a traction pack isolated. There are also occasions where units or locomotives are in traffic with less than designed traction capability due to ongoing faults or failures. In many cases the power available in the degraded mode is theoretically adequate to meet the requirements of the timetable. However, under autumn conditions where the key determinant of time keeping is not installed power but the level of adhesion available to the motored axles, any reduction in the number of axles used to transmit available power can impact on time keeping.
- Autumn timetables – the report emphasised that it may be appropriate for the industry to revisit the extent to which timetable alterations for the autumn period could be beneficially deployed and gave a skip-stop contra-peak service during the AM and PM peaks as an example of a successful autumn timetable on London Midland.

A new strategy

The report concluded that **the industry should now start to consider a new strategy for managing autumn over the next 15 to 20 years. This should be based upon an understanding of the level of adhesion that will need to be consistently achieved in order to support the intensity of operations expected. This should examine the extent to which improvement can be derived from:**

- **a significant change in vegetation strategy;**
- **the exploitation of further developments in train braking, WSP and sanding systems;**
- **technical innovation such as magnetic track brakes (MTBs), the development of aerodynamic modifications to trains to direct leaves away from the wheel-rail interface, and better understanding of the 'wet rail' phenomena and its mitigation.**
- **the opportunities provided by the use of service trains to lay adhesion modifier;**
- **the design and development of the next generation of railhead treatment equipment (offspring of MPV).**

It was also suggested that there was opportunity for commissioning the design of an appropriate series of autumn trials. The evaluation of the measures that could lead to significant long-term autumn performance improvement needs to be set in the context of understanding the industry business case. This will allow necessary levels of investment.

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A9.8 Review of Merseyrail's autumn 2013 by Plurel

Due to problems with low adhesion on the Merseyrail network in the autumn of 2013, Merseyrail and Network Rail commissioned Plurel to carry out an independent review of the measures taken in autumn to prevent or mitigate low adhesion. The goal was to gain insight into achieving the punctuality and operational safety goals, and to indicate which possible improvements can be implemented by Merseyrail and Network Rail in their Low Rail Adhesion Strategy. The following sets out the key observations and conclusions relevant to the GB railway as a whole.

Observations

- The Merseyrail network has very unfavourable conditions for adhesion due to the cuttings and high levels of humidity in autumn. It is therefore admirable that in spite of this they have managed to achieve such a high score on the Public Performance Measure (PPM). Merseyrail and Network Rail have high goals with regards to safety and punctuality.
- Large amounts of leaves immediately alongside the rails form a source of low adhesion. Removing the vegetation in the cuttings is labour intensive. Vegetation management has not been as good in recent years as it was 10 years ago (from interviews). This has resulted in slippery rails in dry periods when there was dew or light rain.
- Merseyrail and Network Rail jointly apply a large set of measures. All in all, the set of measures is more than comprehensive. Theoretically each of the measures individually has positive effect on adhesion. There are some doubts regarding the robustness and implementation of mainly vegetation management, water jetting and the MPV. The effect of the measures was never established by taking testing and measuring.
- It has become clear that sometimes four or five measures (water jetting, Sandite, traction gel, sand from trains, sand by the Mobile Operations Managers (MOMs)) are applied at a single location (close to stations). It is possible that slipperiness may occur due to the use of several agents one after another.

Conclusions on improvements

- There is room for improvement by tackling the source of reduced adhesion, the correct selection of measures, measuring the effect, and fine tuning during autumn.
- More specifically, the improvements that can be achieved are the reduction of vegetation, clearing leaves after they have fallen, determining the effectiveness of sand and Sandite, improving the effectiveness of Sandite by for example better adjustment of the system or lower application speed of the MPV. Once the effects of the measures have been determined then it can be decided whether the other measures should be dropped because they do not contribute to improvement.
- Further insight into the situation that has developed can be enhanced by a qualitatively good visual inspection. Any insight gained from inspections and the low rail adhesion reports from the driver can then be used for interim adjustments.
- The adhesion levels and the condition of the rails at overruns are barely known. If that were to be the case (no Sandite on the rails, excessive leaves, etc.) then it would have been possible to estimate the achievable improvements. That is currently not possible.

Conclusions on safety and punctuality

- The increase of less than 10 overruns up to 2011 to more than 20 after 2011 cannot be explained from the changes in measures. The measures that were introduced in 2012 do not negatively affect the number of overruns. The great number of overruns could be caused by an unfavourable autumn for adhesion in combination with increasing vegetation or due to unknown changes in the measures.
- The risk for low adhesions will, considering the location of the lines, the atmospheric humidity and the large amount of greenery, always exist; and overruns therefore too. The number of overruns should be reduced by applying the above mentioned improvements.
- Defensive driving has a much larger influence on the punctuality than overruns or maintenance. Defensive driving quickly results in delays of more than five minutes per run and a drop of 3% on the PPM per line. It is therefore very difficult to achieve the goal of 91% with defensive driving. Loss of time due to traction slip has not yet been included in the calculations.

A9.9 European review to establish best practice (2016)

In 2016, RSSB conducted a knowledge search (S250) to identify what may constitute best practice for short, medium and long-term safety and performance strategies for train operations in autumn. Practice in Northern Ireland, Germany, Portugal, Switzerland, Australia and Great Britain were reviewed, recognising that the risk from low adhesion varied due to differences in operating infrastructures and service level requirements. The review highlighted the benefits of a national level strategy in addition to daily operations. It recognised and confirmed the following as good practice:

- **Immediate action – enhance data collection processes toward a systematic and consistent approach by listing and comparing local data collection practices. This could be used to identify best practice, gaps and further standardisation;**
- **Short-term action – develop a National Risk Register to identify autumn risk locations at local and national levels to justify mitigations. The Register would include associated location history, Geographical Information System data, industry standards, safety and performance data, vegetation management and railhead treatment specification;**
- **Medium-term action – develop a National Railhead Treatment Programme, with an expert steering group comprising a national weather specialist, route seasons delivery specialists and NSC seasonal specialists. The purpose of this group would be to ensure savings can be achieved through improved train and operating efficiency;**
- **Long-term action – design a National Vegetation Management Programme to manage and audit processes that maximise cost effective strategies to promote safety and performance benefits on priority and key locations.**

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A10 Key recommendations

The following lists the recommendations made throughout this manual and which are **highlighted in orange**.

	Section	Recommendation
1	3.3.2	The lower SPAD risk and reduced impact on performance mean that cautioning on the move using GSM-R berth-triggered broadcasts is the recommended method of warning drivers of low adhesion conditions when the signalling system allows.
2	4.5.1	Priority should be given to the running of the treatment train as failure to do so may lead to significant delays and safety of the line implications for following service trains; it must not be cancelled unless absolutely essential.
3	6.1.3	Train Operated Warning Systems (TOWS) should be taken out of use.
4	A2.2.5	Railhead treatment should be used to improve traction where acceleration problems occur particularly on gradients or on the exit of stations.
5	A2.2.5	The definition of treatment sites should be a dynamic process and should take account of the local knowledge of drivers who regularly operate the route, as they are best placed to say where they normally experience adhesion problems……best practice would be to move away from fixed signage to GPS control as this more easily accommodates such changes, as well as reducing the need for track maintenance.
6	A2.2.11	Operating instructions must consider the likelihood of unfitted trains entering TCAID equipped routes, and a TCA failure must be indicated to the driver who can then follow appropriate procedures in conjunction with the signaller;
7	A2.3.5	TCAs can only be used with certain types of track circuit. It is very important that the compatibility between TCA and track circuit type is assessed prior to using TCA fitted vehicles over routes not previously traversed with such equipment.

	Section	Recommendation
8	A2.3.2	In order to minimize the risk of avoidable damage to the UK railway infrastructure, WSP systems fitted to rolling stock intended for operation over the UK railway network should be optimized for the lower levels of adhesion typically encountered on the UK infrastructure …… AWG recommends WSP manufacturers and vehicle builders continue to use a simulation approach, using naturally occurring variable low adhesion conditions to produce a better performing WSP under real low adhesion conditions.
9	A2.3.3	Sanders should be treated as 'safety critical' and appropriate instructions put in place for managing trains with empty sand boxes…… The inclusion of sand box level detection in the design, flow rate monitoring or usage calculations based on, for example, WSP activity and sanding rate, should be considered to provide targets for monitoring and inspection.
10	A2.3.3	Drivers must be instructed not to apply sand when the train is passing over points and crossings.
11	A2.3.3	All operators are obliged under Health and Safety Regulations to have a COSHH statement on this issue and to have suitable practices in place to minimise the health risk (when filling sand hoppers)…… A mask to protect nose and mouth, together with eye protection, is recommended…… A hopper design with a filling aperture that is as large as practical will make the process easier.
12	A2.3.5	TCAs can only be used with certain types of track circuit. It is very important that the compatibility between TCA and track circuit type is assessed prior to using TCA fitted vehicles over routes not previously traversed with such equipment.
13	A9.5	Wheel contamination should be considered as a significant factor in the braking performance of trains.
14	A9.5	Water jetting and Sandite treatment provides the best method for improving adhesion in autumn conditions and should be used where possible.

	Section	Recommendation
15	A9.6	Sites identified as risks for freight trains stalling should be risk assessed and incorporated, as necessary, into the railhead treatment programme, with TGAs fitted if appropriate. Network Rail Routes, in conjunction with freight operators and in consultation with passenger operators, need to identify locations where the delivery of 'clear run' conditions would reduce the risk of freight trains stalling on rising gradients.
16	A9.6	A key element in robust planning is optimising the engineering possessions to enable the proposed circuits to be delivered without conflict with engineering work. This should take place in the early stages of the planning cycle.
17	A9.6	The review found that TGAs were beneficial and that, subject to appropriate maintenance and overhaul arrangements, reliable……Routes need to ensure that there is a regular review process to identify any reallocation of TGAs required as a result of changes in service pattern or traction type.
18	A9.7	The industry should now start to consider a new strategy for managing autumn over the next 15 to 20 years. This should be based upon an understanding of the level of adhesion that will need to be consistently achieved in order to support the intensity of operations expected. This should examine the extent to which improvement can be derived from: ▶ a significant change in vegetation strategy; ▶ the exploitation of further developments in train braking, WSP and sanding systems; ▶ technical innovation such as magnetic track brakes (MTBs), the development of aerodynamic modifications to trains to direct leaves away from the wheel-rail interface, and better understanding of the 'wet rail' phenomena and its mitigation. ▶ the opportunities provided by the use of service trains to lay adhesion modifier; ▶ the design and development of the next generation of railhead treatment equipment (offspring of MPV).

	Section	Recommendation
		It was also suggested that there was opportunity for commissioning the design of an appropriate series of autumn trials. The evaluation of the measures that could lead to significant long-term autumn performance improvement needs to be set in the context of understanding the industry business case. This will allow necessary levels of investment.
19	A9.9	The review of practice across Europe recognised and confirmed the following as good practice: ▶ Immediate action – enhance data collection processes toward a systematic and consistent approach by listing and comparing local data collection practices. This could be used to identify best practice, gaps and further standardisation; ▶ Short-term action – develop a National Risk Register to identify autumn risk locations at local and national levels to justify mitigations. The Register would include associated location history, Geographical Information System data, industry standards, safety and performance data, vegetation management and railhead treatment specification; ▶ Medium-term action – develop a National Railhead Treatment Programme, with an expert steering group comprising a national weather specialist, route seasons delivery specialists and NSC seasonal specialists. The purpose of this group would be to ensure savings can be achieved through improved train and operating efficiency; ▶ Long-term action – design a National Vegetation Management Programme to manage and audit processes that maximise cost effective strategies to promote safety and performance benefits on priority and key locations.