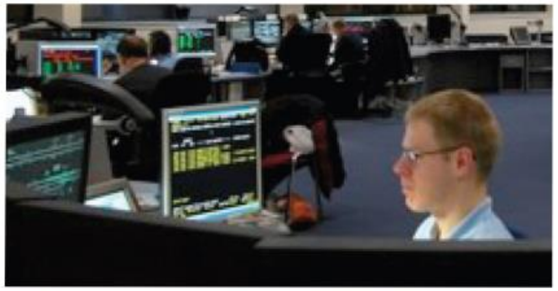
Managing Low Adhesion

Seventh Edition, May 2024

Rail Delivery Group

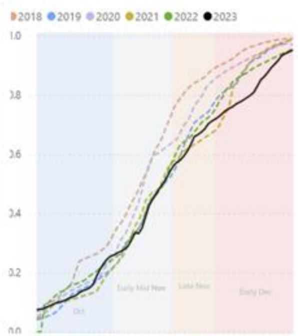
National Rail

SCSG







Edition 7, May 2024

Managing Low Adhesion

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Foreword

As Chair of Seasonal Challenge Steering Group (SCSG), I would like to welcome you to the seventh edition of the "Managing Low Adhesion" manual – the repository of our industry's corporate knowledge on understanding and managing low adhesion. This manual is not a 'standard' or part of the Rule Book, it is a reference book explaining:

- The root causes of low adhesion caused by railhead and wheel tread contamination, whether it is caused by leaf fall in Autumn or other contaminants throughout the year.
- Proven and emerging best practice used in Britain to combat its effects.

This manual aims to support a diverse community of practitioners and assurers in helping them improve safety and performance during low adhesion conditions, thus improving customer experience. For example:

- Network Rail's Seasons Delivery Managers and Specialists in preparing for the low adhesion season;
- Train / freight operator Driver Standards Managers and Fleet Engineers to inform their training, processes and standards;
- Train / freight operator and Network Rail Operations Controllers to support operational decisions;
- Train / freight operator and Network Rail Managers investigating incidents;
- Joint performance teams in Network Rail and the train operators who develop and manage performance plans;
- Network Rail Supply Chain Operations to help them understand the why and how of what they do;
- The supply chain and innovators by helping them understand low adhesion and the whole railway system context.

This edition of the manual captures key findings from investigations and R&D that have taken place since it was last issued in 2018, not to mention improvements in how the industry manages low adhesion – the most significant of which is the advent of SCSG's "GB Rail Industry Approach to Railhead Adhesion Management" which this manual complements. The 'GB approach' explains **what** is required, by **whom** and **when**, referencing this manual to explain **how** it can be done.

Managing Low Adhesion

This is the first edition of the manual to be published by SCSG, which took over from the Adhesion Working Group (AWG) as the industry's adhesion champion in 2019. I would like to dedicate this edition of the manual to Adrian Shooter CBE, who had the vision to bring the newly privatised railway together to address adhesion by setting up AWG in 1995 and leading it for many years.

Like my predecessors at the helm of AWG, I welcome the enthusiasm of many people from various parts of the industry who have contributed directly or indirectly to this manual. I would, in particular, like to thank the Editorial Committee below who were responsible for this update.

I would also like to thank those who take time out of their busy day jobs to serve on SCSG, Seasonal Challenge Communications Group (SCCG), Adhesion Research Group (ARG), and who served on AWG before them. Through all their hard work, the industry recognises the value of these groups as a 'centre of knowledge and excellence' for reducing the impact from adverse weather during all seasons, not just the Autumn.

Please take time to read through this manual. By understanding the issues and adopting some of the good practice described, hopefully we can all contribute to mitigating the effects of low adhesion caused by railhead and wheel tread contamination, and help to run a normal timetable safely and punctually during the Autumn. Suggestions on how we can improve both our management of low adhesion conditions and this manual can be submitted to SCSG via your representative.

There can be no complacency as the tragic accident at Salisbury reminds us, and the short leaf fall period still produces disproportionate delays even though low adhesion is not just an autumn problem!

Lisa Angus
Chair, Seasonal Challenge Steering Group
Industry Weather Response Director, Network Rail
May 2024

Edition 7, May 2024

Edition 7, May 2024

Managing Low Adhesion

About the Seasonal Challenge Steering Group

The Seasonal Challenge Steering Group (SCSG) is the coordinating body for seasonal review and management within the GB mainline rail industry:

- SCSG aligns industry partners with a focus on understanding, reporting and actively reducing seasonal performance impact.
- SCSG provides support to passenger train and freight operators, and Network Rail (NR) on issues which are flagged through the Joint Seasonal Management Group (JSMG).
- SCSG has the authority to propose new initiatives on behalf of the Network Performance Board (NPB), and a key priority in looking ahead is to be more ambitious and more prescriptive in terms of how improvement can be generated across the different seasons.
- With so much learning to be shared across our industry, SCSG has the opportunity to drive the change that will deliver better outcomes. This manual and the "GB Rail Industry Approach to Railhead Adhesion Management" is an example of such learning.

SCSG's relationship with other industry groups is shown adjacent. SCSG reports to RDG's Network Performance Board and has a communications sub-group (SCCG). SCSG and SCCG maintain close links with the industry's strategic Adhesion Research Group (ARG); the industry sponsor for adhesion related research proposals to RSSB. SCSG and SCCG focus on the more immediate needs of train operators and Network Rail across the seasons, while longer-term R&D on adhesion is managed by ARG, with appropriate input from SCSG and SCCG.

Edition 7, May 2024

Managing Low Adhesion

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Acknowledgements:

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Edition 7, May 2024

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How to use this manual

- **This manual is primarily designed for viewing on a screen rather than hard copy. It is best viewed using Adobe Acrobat (free) PDF viewer or any equivalent application that permits the 'bookmarks' pane to be visible, showing the structure of the manual and allowing easy navigation to any part. If reading in print form, section 9 provides advice on where to find more information.**
- This manual can be read from beginning to end, but it has been structured to facilitate its use as a text book to seek information on a particular topic.
- This manual is not a standard or part of the Rule Book. If there is any conflict with legislation and standards, then they prevail. No information within this manual should be considered as modifying or replacing legal duties, national standards, operating rules or company policies and procedures.
- Hyperlinks direct to standards and other material published by NR and RSSB have been minimised because they are likely to change within the life of this edition of the manual. Again, section 9 provides advice on where to find them on-line.

Edition 7, May 2024

Managing Low Adhesion

SCSG

Disclaimer

- The Seasonal Challenge Steering Group is not a regulatory body and compliance with this manual is not mandatory. The guidance in this manual reflects good practice and is advisory only.
- Users are recommended to evaluate the guidance against their own arrangements in a structured and systematic way, noting that parts of the guidance may not be appropriate to their operations. This process of evaluation and any subsequent decision to adopt (or not adopt) elements of the guidance should be documented. Compliance with any or all of the contents herein, is entirely at an organisation's own discretion.
- This manual is published without responsibility on the part of SCSG or the Editorial Committee for loss occasioned to any person or organisation acting or refraining from action as a result of any information that it contains.
- References in this manual to products, services and companies does not imply that SCSG or the Editorial Committee endorse them, and alternatives may exist offering similar or improved capability. However, it represents best current knowledge and future editions of the manual will continue to expand on this as new solutions are developed.
- OEMs continue to deliver their own privately funded R&D to inform product development, some of which may not be in the public domain. R&D identified in this manual cannot therefore be a definitive list.
- The industry continues to develop and evolve its approach to low adhesion. Improvements will be introduced, and the content of this manual will then be out-of-date until the next update. Every effort has been taken to check the accuracy of the manual at the time of publication, but suggestions on how it can be improved are welcome via your SCSG representative.

Managing Low Adhesion

Contents

Edition 7, May 2024

Edition 7, May 2024

1 Introduction

Railways move large volumes of passengers and freight using steel wheels on steel rails. This means that rolling resistance is low, so these loads can be hauled very efficiently. One of the downsides, however, is that the friction between the wheel and rail varies considerably with the effects of moisture, rust, leaf fall and other contaminants – some of which cannot be easily monitored or controlled.

Adhesion is the level of friction between the wheel and the rail and it enables trains to accelerate and brake effectively. Low adhesion, caused by contaminants between the wheel and the rail, limits a train's ability to accelerate and brake. The lower the adhesion, the lower the acceleration and braking rates that can be accommodated before the wheels spin or slide on the rails.

Whilst Britain's mainline railway is predominately affected by low adhesion during the Autumn, it can be seen throughout the rest of the year. Wet rails, accompanied by rail-borne contaminants, can offer low adhesion levels despite the rails looking clean.

Low adhesion causes a number of problems:

- Reduced ability to stop trains potentially leading to Signals Passed at Danger (SPADs), station platform overruns, buffer stop collisions (Chester 20 November 2013) and train collisions (Salisbury 31 October 2021);
- Reduced ability to start trains, accelerate and maintain speed leading to lengthened journey times for passengers and freight;
- Damage to train wheels requiring trains out of service for tyre re-profiling (derailment at Petteril Bridge Junction 19 October 2022, where the initial wheel slide was probably the result of a brake application made in low adhesion conditions but wheel slide continued because the adhesion between the wheels and the rails was then insufficient for the wheels to restart rotation);
- Damage to rails requiring regrinding and premature replacement (Pencoed and Llanharan 6 March 2021);

Edition 7, May 2024

- Contamination can also electrically insulate the connection between the wheel and rails, leading to Wrong Side Track Circuit Failures (WSTCFs) (Norwich Road level crossing 24 November 2019) and potentially collisions.

In their Annual Report for 2022, RAIB states: "*....issues with adhesion have existed for as long as the railway and are an inherent part of it; considerable vigilance remains necessary if accidents, such as those we have seen recently, are to be avoided.*" This manual facilitates that vigilance by explaining the phenomenon of low adhesion and the best practices used in Britain to mitigate its effects. The structure is as follows:

- Low adhesion is explained in section 2;
- Measures for its management across operations, infrastructure, rolling stock and train detection are explained in sections 3 to 6 respectively;
- Abbreviations, explanations of terms, and references used are listed in sections 7 to 9 respectively;
- Appendices A1 to A8 provide supporting detail.

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

Key recommendations are **highlighted in orange** and summarised in appendix A8. Text in *italics* is quoted from other documents. **Bold** is used for emphasis.

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2 Low adhesion

This section explains low adhesion in the following sub-sections:

- What is low adhesion?
- Why is it such a problem to a modern railway?
- How is low adhesion 'activated'?
- What is the impact?
- How is it being managed?

2.1 What is low adhesion?

Put simply, adhesion is a measure of the grip or slipperiness between the wheel and rail. It is normally expressed as the coefficient of friction 'μ' (pronounced 'mew') – a decimal fraction or sometimes a percentage:

- 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 dry road surface, the adhesion is 0.85 or higher.

Adhesion limits the amount of braking or acceleration that can be demanded without the wheel sliding or spinning on the rail. When μ is expressed as a percentage of the acceleration due to gravity (often called 'g'), it is roughly equivalent to the maximum rate of deceleration possible when braking. 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, adhesion needs to be at least 0.09 (9%) to avoid suffering wheel slide during braking. For simplicity, the remainder of this manual refers to the level of adhesion as a percentage.

For traction purposes however, the adhesion level needs to be higher to start a train without the wheels spinning, ranging from 15% for a typical 4 car multiple unit, up to about 25% for a locomotive hauling a heavy freight train. This depends on factors such as the: number of motored axles; gradient; the axle loads; and, the trailing load, etc. This means that it is typically more difficult to deliver the adhesion required for traction than it is braking.

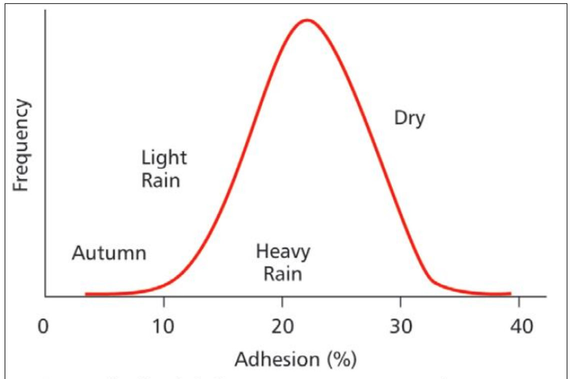
In dry weather with clean (shiny) uncontaminated rails, the adhesion would commonly be between 20% and 40%, whilst in really wet conditions it may be between 10% and 20%. Neither circumstance should cause braking problems. Occasionally, however, much lower levels of adhesion are encountered particularly in the Autumn when moist crushed leaves on the rails can reduce levels to as low as 1%; 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.

Low adhesion can be classified into a number of distinct bands:

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 

On the rare occasions when the rails are severely contaminated, such as with dampened leaves, the adhesion level can be extremely low – levels as low as 1% have been recorded. Here other measures are necessary to compensate, such as the application of sand, c.f. gritting icy roads. Modern passenger trains which demand higher rates of deceleration are equipped with WSP and sanders to mitigate the effects of low adhesion.

From surveys in the 1990s by the British Rail Tribometer train, the adjacent graph shows the variation of adhesion levels on the railway. Exceptionally low levels of adhesion (below 5%) are rare as indeed are 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

2.2 Why is it such a problem to a modern railway?

The railways have operated with the same basic steel wheels on steel rails 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 is energy efficient; the low rolling resistance considerably reduces the effort required to move heavy loads. However, this advantage can be the railway's Achilles heel. The areas of contact between wheel and rail, known as the 'contact patch', is the size of a small coin at just 1cm^2. During the autumn leaf fall, but not only at this time, the rail surface and the wheel treads can become coated with a range of contaminants causing low adhesion.

The most renowned cause of low adhesion is of course leaf contamination from lineside vegetation, which is not a new problem and has been suffered for decades. However, there are many causes:

- Crushed leaves rolled on the rails by passing trains activated by moisture;
- General moisture / dampness (dew, condensation, ice) mixed with contaminants on the rail such as rail wear debris or rust;
- The onset of light rain / drizzle after a dry period;
- Solid particulates from loading / unloading freight wagons;
- 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.

These causes can be split into those that the railway has little or no direct control over (naturally occurring conditions) and those that are directly under the railway's control ('man-made' conditions). Seeking co-operation from the railway's neighbours can also reduce the impact when the cause comes from beyond the railway boundary.

Edition 7, May 2024

Managing Low Adhesion

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:

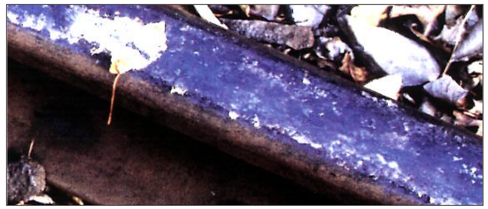
- The temperature and humidity levels can change rapidly;
- Contaminants react differently to the passage of a train;
- The trains are driven differently;
- The trains themselves are different.

Furthermore, 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 next few pages explore causes of low adhesion in more detail:

Leaves

A significant cause of low adhesion is the 'wrong type of leaves' crushed onto the railhead by the train's wheels to form a hard 'Teflon' type coating on the rails due to the immense contact pressure of up to 50,000 tonnes/m^2 (equivalent to the weight of two double decker buses on a postage stamp). It is known that leaves are drawn into the wheel / rail interface by the aerodynamic effects of passing trains and crushed under the wheels; leaves falling many metres away from the railhead can subsequently be blown onto it. This hard coating can cause track circuit operating difficulties when it is dry (acting as an electrical insulator) and cause braking difficulties when damp (acting as a lubricator). With very wet conditions, the crushed leaves are softened and the layer is then broken up by the action of passing trains and washed off the rails by the rain. However, testing has shown that the coating can re-form after the passage of just a few trains, if the right drying weather conditions are present.



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 and is difficult to scrape off. Furthermore, it has been shown that leaf matter is transferred by the train wheels further along the track, up to half a mile beyond the trees in extreme cases.

Not all leaves are a problem and selectively combating vegetation will pay dividends by reducing cost and minimising the environmental impact.

During 2007, AEA Technology Rail and Newcastle University investigated the characteristics of railhead contamination to improve the industry's understanding of how leaf contamination bonds to the railhead (RSSB R&D project T354).

Leaf films were artificially created using real leaves crushed onto real rail on a full-scale wheel-on-rail rig (adjacent). Analysis of leaf films concluded:

- Analysis of three different leaf types (Horse Chestnut, Sycamore and Oak) validated the technique of leaf film creation using the full-scale wheel on rail rig;
- 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;
- A hypothesis for the low adhesion between the top side of the leaf film and wheel is that 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 research on the biochemistry of leaf contaminated films on railheads. Five main research institutions were identified as leaders in the field, wherein some research

Edition 7, May 2024

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.

In 2022, RSSB work with the University of Huddersfield on highly adherent leaf layers (RSSB R&D project COF-UOH-72) using their Huddersfield Adhesion and Rolling Contact Dynamics (HAROLD) test rig (adjacent) found that:

- Leaf type was shown to be the most statistically significant factor in the bonding strength of the leaf layer;
- Higher wheel loads generate thinner and more bonded leaf layers;
- Wheel load was shown to be the only input or interaction that had a statistical significance on the resulting adhesion levels;

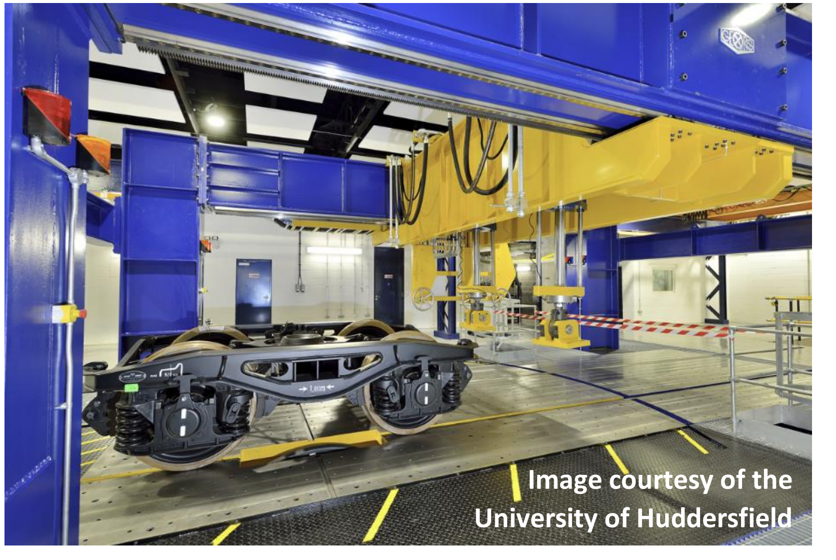


Image courtesy of the University of Huddersfield

Edition 7, May 2024

- Leaf layer spread / transfer showed that as few as 5 leaves applied to approximately 1.6 m of rail can produce a consistent black leaf layer around the whole wheel and rail roller of the test rig. This has shown that bulk leaves are not necessarily needed to create a highly adherent leaf layer.

Rain / Moisture

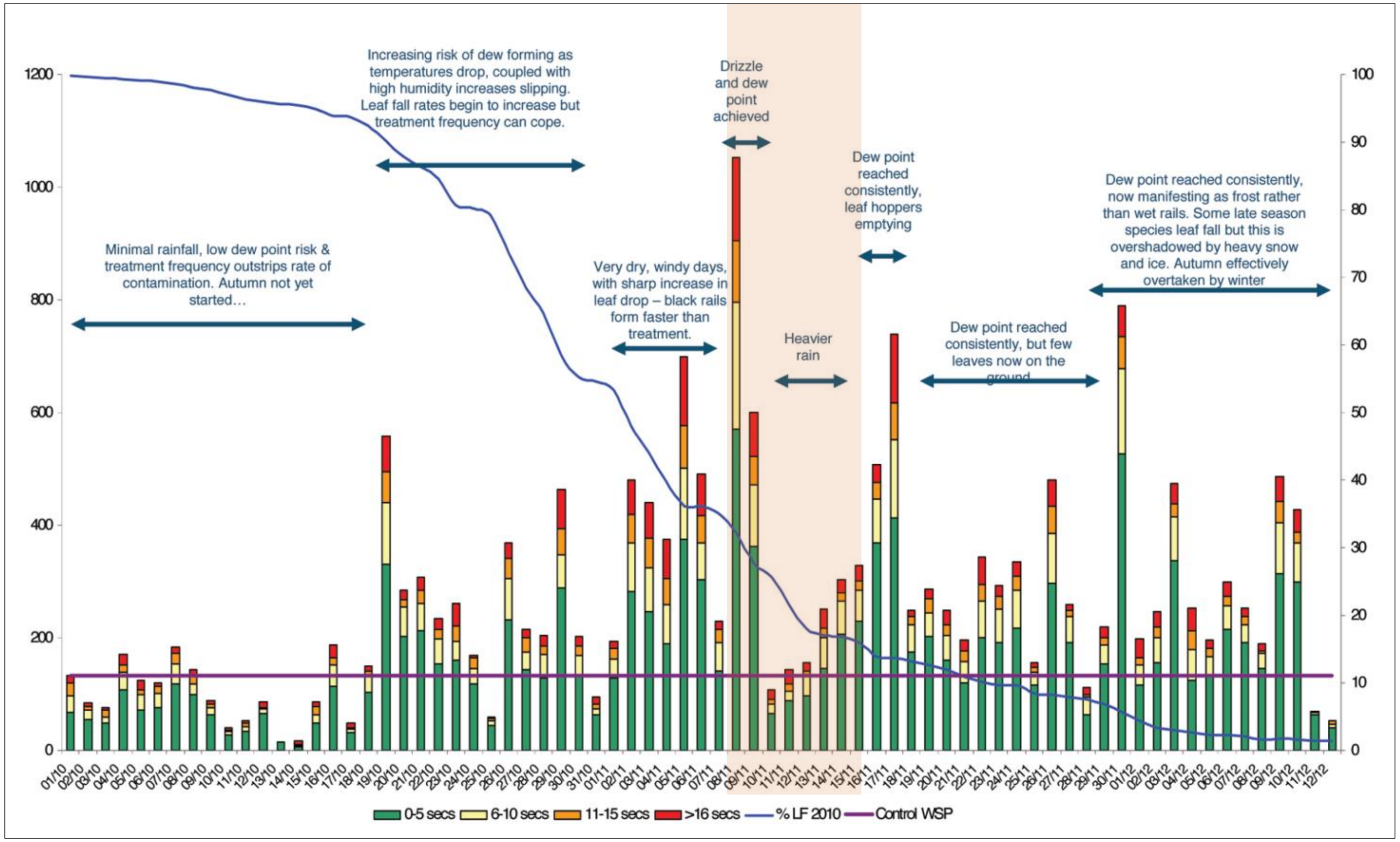
Small amounts of water are the most common catalyst for low adhesion such as: very light drizzle; dew; high humidity or misty conditions; condensation forming on the rails; or, when the rails are drying after rain. These are the times when low adhesion conditions are most likely to arise. If this is 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.

However, heavy rain can improve adhesion by washing contaminants off the rails and helping to keep fallen leaves on the ground and not be lifted by air turbulence from passing trains. It would not normally reduce adhesion levels below that required for normal train operation.

Water-Trak

Using a controlled amount of water to create 'rainy day' braking conditions can provide a step-change improvement in both braking and traction. Following initial feasibility and demonstration projects funded by the RSSB-led Innovation Programme, Water-Trak Ltd was formed to exploit the technology. It has now recorded around 80,000 miles of data, with retrofitting on several of Northern Trains Class 319s and Class 170s. In Full Service braking, a Water-Trak fitted Class 319 with single variable rate sanders demonstrated a 40% reduction in stopping distance compared to without Water-Trak. See section A1.5.8.

The chart below correlates wheel slide duration (as an indicator of low adhesion) with factors that lead to the rails being wet during a leaf fall season. Recognising there are many factors at play; when most leaves are on the ground the peak on the 8 November coincides with drizzle and reaching dew point, whilst the dips on 10-15 November coincide with heavier rain.



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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;
- Close to 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.

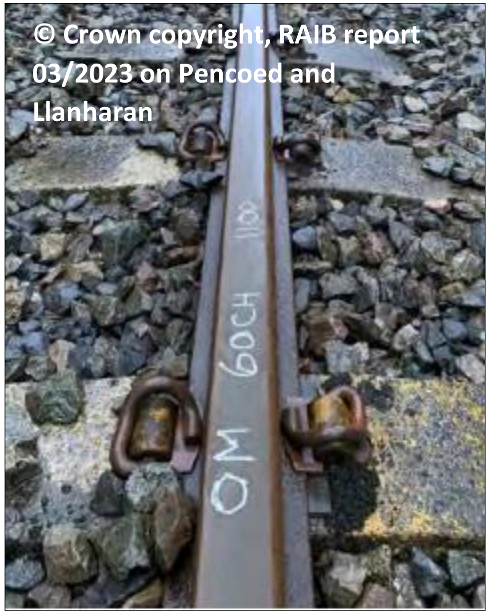
Oily Matter

Oil is the next most common catalyst for low adhesion after moisture. Oil can come from a variety of sources such as: fuel and lubricating oil drips from rolling stock; hydraulic oil spillages from track machines; grease from misaligned flange lubricators; and, aviation fuel near airports. 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. Moisture added to this will compound the effect on adhesion.

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), which can 'mop up' oils by absorption. The most significant effect of rust is when combined with small amounts of water.

The adjacent photo is taken from RAIB's report into Pencoed and Llanharan, the summary of which states "*The rails on that line were rusty as it had not been used for several months. The environmental conditions were such that the rails were also wet, and it was the combination of rust and moisture which created the very low adhesion experienced by the train.*" This led to flats during a braking event which caused track damage from impact loading.

Solid particulates

Certain solid materials in the form of particulates can become a problem particularly when subject to moisture. For example:

- Clay / cement where these are loaded / unloaded into freight wagons;
- Iron ore pellets have been known to cause the same effects as moist rust on the railhead;
- Road vehicles at level crossings bringing mud, oil, water and other deposits onto the railway;
- Silt after flooding.

Edition 7, May 2024

2.3 How is low adhesion ‘activated’?

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 adding a small amount of water ‘activates’ the contaminant. 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 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 activate these low adhesion conditions.

In 2014, RSSB R&D project T1042 investigated the effects of moisture on rail adhesion concluding:

- The adjacent definition of the 'Wet Rail Phenomenon’;
- When visible contamination is present on the railhead, it will dominate the adhesion characteristics between the wheel and the rail (but see note below);
- 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 this impact is most significant when the levels of moisture are low (as long as there is no contaminant present);
- Performance data suggests that colder average air temperatures can significantly influence adhesion performance, possibly due to autumn frosts accelerating greater levels of leaf fall.

> **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.*
> RSSB R&D project T1042

Note though, that low adhesion isn’t just limited to visible contamination. “*More than two thirds of Safety KPIs in autumn occur with no visible contamination present…The reliable confirmation (within an operational context) of Non-Visible contamination when associated with a loss of adhesion or loss of detection remains a continuing challenge*” (“Operational detection of non-visible contamination of railhead – Synopsis” Network Rail, 2021). In June 2023, ARG summarised this: "*It is important to note ARG's view that clean rails do not necessarily provide good adhesion…ARG sees no value in processes that fail to demonstrate improved adhesion from a low adhesion start point. A visual improvement in 'cleaner' wheels or rails has little or no value*" (ARG paper, June 2023).

T1042 suggested that two main scenarios lead to low adhesion events, 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, i.e. during the transition phase from very wet rail head (reasonable adhesion) to damp rail head (poor adhesion).

Further insight into the 'Wet Rail Phenomenon' came from a PhD in conjunction with the University of Reading and TRL (RSSB R&D project COF-TAR-04). Laboratory testing examined 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.

In 2016, the University of Sheffield built on this by developing a model to predict the effect of water in the wheel / rail contact patch, and validate this with representative full-scale testing (RSSB R&D project 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 results 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 effects.

Working with the University of Huddersfield, T1077 was subsequently integrated into the Low Adhesion Braking Model, LABRADOR, (RSSB R&D project COF-UOH-LAB) which simulates train braking behaviour to support investigation of specific brake control features such as: WSP; sand application; dynamic brake utilisation; and, traction performance in low adhesion conditions. This capability was subsequently extended to include the Leaf-Induced Low Adhesion Creep (LILAC) force model developed under RSSB R&D project T1149.

2.4 What is the impact?

What is the safety risk?

The main safety risk from low adhesion arises from trains sliding through stations, open level crossings, passing signals at danger and collisions with other trains or buffer stops. RSSB has estimated this risk to be around 0.1 Fatalities and Weighted Injuries (FWI) per year (based on data up to and including FY 2019/20, therefore excluding Salisbury). Whilst this risk is 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 and wider society was estimated by RSSB in 2019 to be approximately £350 million each autumn. This arises from many different causes some of which are difficult to quantify:

- Signals Passed at Danger (SPADs) and Station Overruns;
- Performance delay minutes, cancellations and the resulting compensation payments;
- Reduced capacity from special leaf fall timetables;
- Lineside vegetation management and leaf fence maintenance;

- Rail Head Treatment Train (RHTT) maintenance and operation;
- Annual commissioning, maintenance and decommissioning of lineside Traction Gel Applicators (TGAs);
- Repairing wheel burns on rails 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;
- Ticket refunds.

This does not include the significant consequences of a serious incident such as a collision or derailment. Note that in their report on the derailment at Petteril Bridge Junction (19 October 2022), RAIB suggested that "*The initial wheel slide was probably the result of a normal brake application made in low adhesion conditions that were not abnormal for the route at the time of year. The wheel slide continued because the adhesion between the wheels and the rails was then insufficient for the wheels to restart rotation.*"

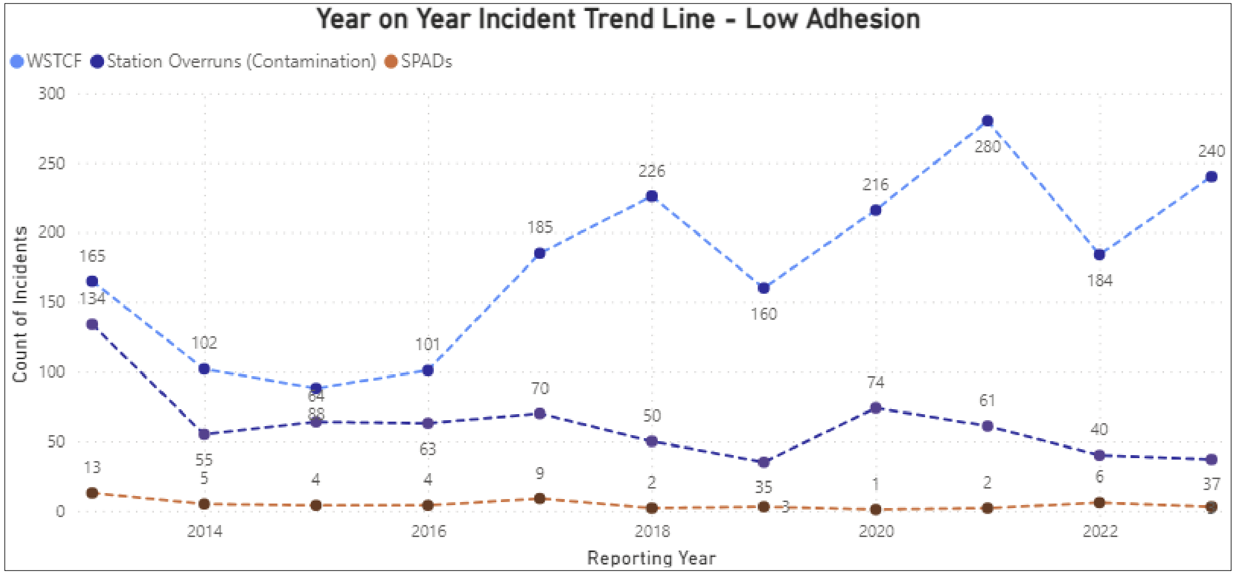
Edition 7, May 2024

Managing Low Adhesion

SCSG

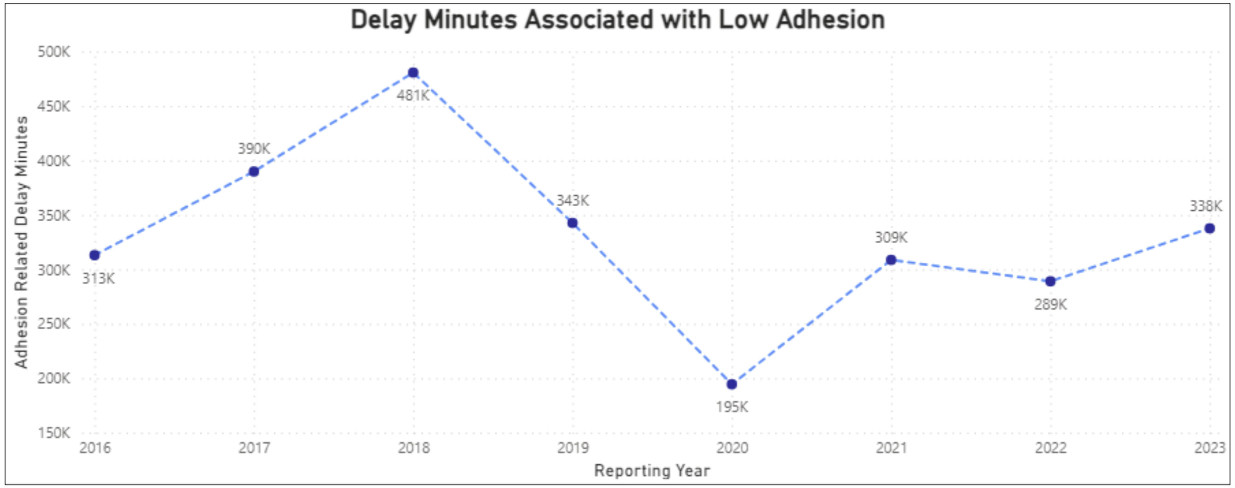
What is the impact on operations?

Low adhesion can cause safety of the line incidents such as SPADs, Wrong Side Track Circuit Failure (WSTCF) and Station Overruns. The graph below shows these KPIs over the past ten years. Whereas the last edition of this manual found a 60% WSTCFs, 37% station overruns and 3% SPADs split in 2016 data, it is now 86%, 13% and 1% respectively. Reported WSTCFs have become much more dominant, in part due to Remote Condition Monitoring (RCM) being increasingly deployed to proactively manage the problem.



Managing Low Adhesion

The second major effect is on train performance, particularly the ability to keep to time. Reduced adhesion leads to the driving wheels spinning. This reduces vehicle acceleration and maximum speed, even leading to heavy freight trains ‘slipping’ to a stand on a gradient (typically when accelerating on rising gradients of 1 in 120 or steeper and when starting on gradients). The graph below shows the autumn delay minutes accumulated across Britain’s mainline railway over the past seven years. Outside 2020 (early COVID lockdowns), in excess of 250,000 delay minutes are typically lost during the months of late October, November and early December. This is the same delay as reported in the last edition of this manual which used 2016 data. However, some context and perhaps some comfort can be gained from the delay in 2003 which was reported to be nearly 700,000 minutes.



2.5 How is it being managed?

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 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 to maximise the quality and safety of the service, as well as minimise costs to keep the railway competitive.

Tactical management of low adhesion – the 'GB Approach'

SCSG's "GB Rail Industry Approach to Railhead Adhesion Management" sets out, in one place, the approach to the management of railhead adhesion on the GB rail mainline network. It was created following requests from rail industry practitioners and assurers, as well as a desire to share initial learning from the collision at Salisbury.

The document aims to:

- Be a single reference source for all relevant proven and practical control measures that will help Duty Holders manage risk arising from poor railhead adhesion;
- Set out future control measures being developed that, if successful, will give new tools for Duty Holders to improve the management of these risks.

The adhesion control measures are intended to reduce the risk to As Low As Reasonably Practicable (ALARP), while allowing the network to maintain operational effectiveness. The three main aims of the control measures are to:

- Prevent or reduce railhead contamination during leaf-fall;
- Remove railhead contamination;
- Mitigate risk caused by railhead contamination.

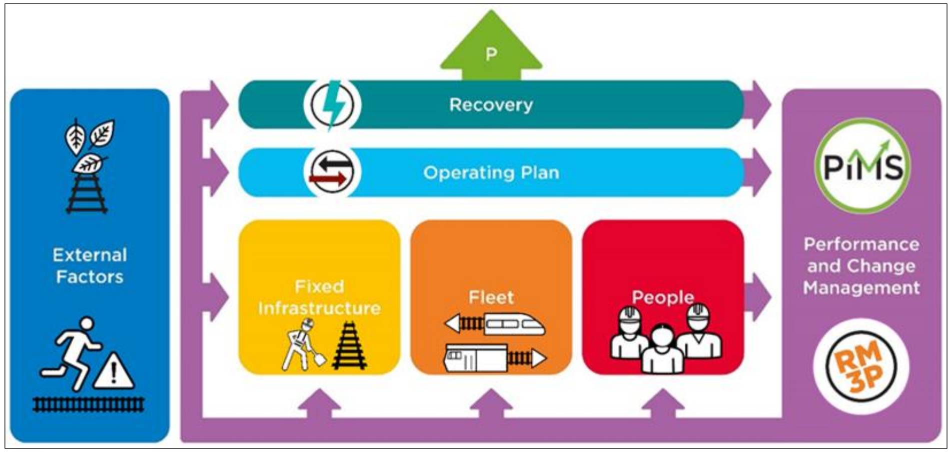
The control measures are explained in this manual.

The GB approach document is updated annually and the latest version can be found here.

Managing Low Adhesion

Routine management of low adhesion

The whole system model underpins the Performance Improvement Management System (PIMS) used by Network Rail to manage operational performance.



Operational performance depends in the first instance on the inputs from:

- Infrastructure such as Traction Gel Applicators (TGAs);
- Rolling stock such as trainborne sanders;
- People such as driver knowledge.

The operating plan must reflect the availability of the inputs, so the Sectional Running Times (SRTs) can reflect what the train can actually achieve for typical adhesion conditions. Recovery plans are then used to get back to running the operating plan. Improvements come under Performance and Change Management, whilst external factors are outside the industry’s direct control, e.g. trees outside the Network Rail boundary when neighbours won’t cooperate.

Investigations and annual reviews

The risk to safety and performance 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 now captured in SCSC's the “GB Rail Industry Approach to Railhead Adhesion Management” (above).

Aside from reviews carried out annually, several additional investigations were conducted between 1999 and 2016 and hence present an historical assessment (appendix A7). The results provide a range of lessons for the whole

Edition 7, May 2024

industry and, **while they do not necessarily reflect current issues**, there are a number of consistent conclusions which remain relevant today:

- Effective autumn response necessitates effective preparation;
- 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;
- Operationally, the Professional Driving Policy remains the most important means of mitigating the effects of low adhesion supported by experience and training, although it may impact punctuality;
- Train sanders have demonstrated their effectiveness as a trainborne mitigation;
- Water jetting combined with adhesion modifier, e.g. Sandite and Traction Gel (TG60), 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.

More recent experience reveals that:

- The ‘Wet Rail Phenomenon’ is a significant cause of problems (section 2.3), recognising that water can also be a solution – by adding it to damp rails, e.g. Water-Trak (appendix A1.5.8).
- Information from drivers and on-train systems is important for identifying high-risk locations as they are not always obvious;
- Forecast information given to drivers must be timely, accurate and easy to understand.

3 Operational measures

The effects of low adhesion cannot yet be completely countered by technical solutions, so operational and management measures play a vital role in mitigating the effects. This section describes these in the following sub-sections:

- Managing the risk;
- Raising awareness among staff, passengers, the public and the media;
- Training and competence of drivers, signallers, control office staff and those analysing train data recorders;
- Timetabling and diagramming;
- Managing adhesion information;
- Responding to low adhesion;
- Performance monitoring.

3.1 Managing the risk

Railway Industry Standard RIS-8040-TOM "Managing Low Adhesion" sets out a framework for managing low adhesion at high-risk sites. Network Rail has set out their requirements for this in NR/L2/OPS/095 "High Risk Sites for Wrong Side Track Circuit Failures in Leaf Areas and for Low Rail Adhesion", which requires Network Rail to:

- Identify the high-risk locations that require a site-specific plan;
- Collaborate to develop plans intended to eliminate or mitigate the risk of low adhesion at identified high-risk sites;
- Implement the measures set out in the site-specific plan;
- Monitor the effectiveness of the measures implemented;
- Review and update site-specific plans to continue to provide the most effective mitigations.

Under ROGS; train operators are required to co-operate with the infrastructure manager and take action to reduce the risks that cannot be eliminated by local treatment at specific sites. This should consider the capability of the trains operating over the sites, including:

- Optimising WSP equipment;
- Sanding equipment;
- Utilising on-train systems to detect wheel slide activity and alert the driver.

Railhead Adhesion Management Plans

The co-ordination of the above activities, their logistics and their integration is a significant project. A joint management process is essential because of the many stakeholders such as train operators, train owners, signallers, and on-track teams. Duty Holders are therefore jointly responsible for producing a Railhead Adhesion Management Plan (RAMP) that will reduce low adhesion risk to acceptable levels. The RAMP defines the mix and scope of control measures for each part of their network and the way they are used. Duty Holders should decide if the plan forms part of an all-seasons weather management plan or stands alone.

It is expected that each RAMP will include some, or all, of the following:

- The contributing Duty Holders;
- The extent of the network to which the plan applies;

- The range, scope and timing of the (infrastructure, trainborne, operational and management) control measures to be used;
- The justification if a control measure will not be used for any reason;
- Which Duty Holder is responsible for implementing which parts of each selected control measure;
- The process for preparing each control measure in advance of the leaf-fall season;
- The process for assuring preparations and use of each control measure;
- The process for assessing the adequacy of the RAMP as conditions change, making suitable changes as necessary;
- The process for identifying other risk mitigations when a planned control measure fails 'on the day';
- The input measures and targets set for the readiness and use of each control measure.

Joint Seasonal Management Groups

SCSG recommends that relevant Duty Holders hold local Joint Seasonal Management Groups (JSMG) to create RAMPs. The Duty Holders should decide the exact form of each group, e.g. name, terms of reference, meeting arrangements, the form of the agreed plan, etc. Each control measure used on the network should have a lead Duty Holder as suggested by the GB Approach (section 2.5), who should satisfy itself that the:

- Control measure is being properly applied in accordance with the RAMP, or escalating the matter to the JSMG if it isn't satisfied;
- Assurance processes that apply to the control measures are fit-for-purpose.

Where assurance processes require joint actions with other Duty Holders, these should be agreed with the other relevant Duty Holders and documented in the RAMP.

SCSG has developed a weather-related maturity model (RM3P) that complements the Industry Risk Management Maturity Model for Performance. This can be adopted by Duty Holders as part of their weather-related assurance processes.

Edition 7, May 2024

3.2 Raising awareness

Raising the awareness amongst stakeholders is essential for confidence in the rail system. It's not easy but it should be tackled on a regular basis to check it remains a well understood problem and to provide reassurance that the problem is being tackled.

This section discusses awareness raising across three groups of stakeholders:

- Staff;
- Passengers, their representative groups and the general public;
- Media and opinion formers (such as politicians).

3.2.1 Staff

RSSB's Right Track newsletter and RED video briefings aim to raise and maintain awareness of key issues amongst front-line staff and managers whether they work in the train cab, signal box or adhesion control. Right Track 44 and Red 66 were both issued in the second half of 2023 and both contained briefings on low adhesion.

These along with other material such as this manual can be used by train operators and infrastructure managers to develop their own targeted briefing and awareness material.

Briefings should normally take place ahead of the autumn season and, once the leaf fall season is underway, further briefings should be undertaken to keep staff advised of progress and performance.

Joint briefings of driver and signaller managers / trainers can add value in raising the awareness of their respective duties and the difficulties experienced – so they can see the other's perspective and understand each other's requirements.

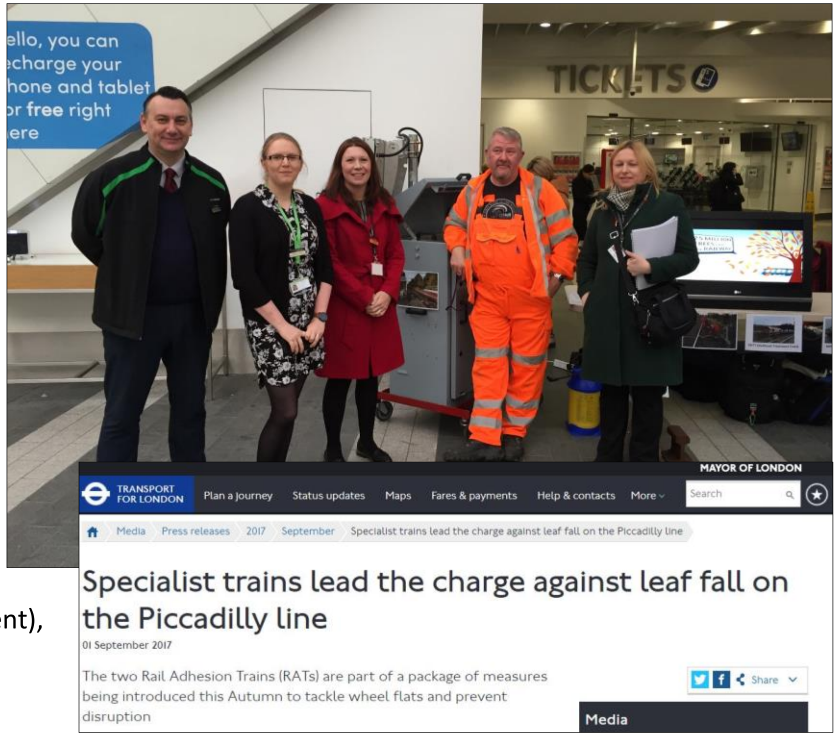
Emerging problem locations require more dynamic provision of information to drivers. There are many ways of doing this, including information monitors at booking on points, train radio broadcasts (e.g. GSM-R), information in the Late Notice Case, specific verbal briefing by driver managers, etc.

Managing Low Adhesion

3.2.2 Passengers and the public

Good public relations (PR) are essential for educating passengers and the general public 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 social media, internet articles (adjacent), leaflets, and posters should also be considered.

Planned proactive PR measures will help to minimise complaints by customers and the general public.

Edition 7, May 2024

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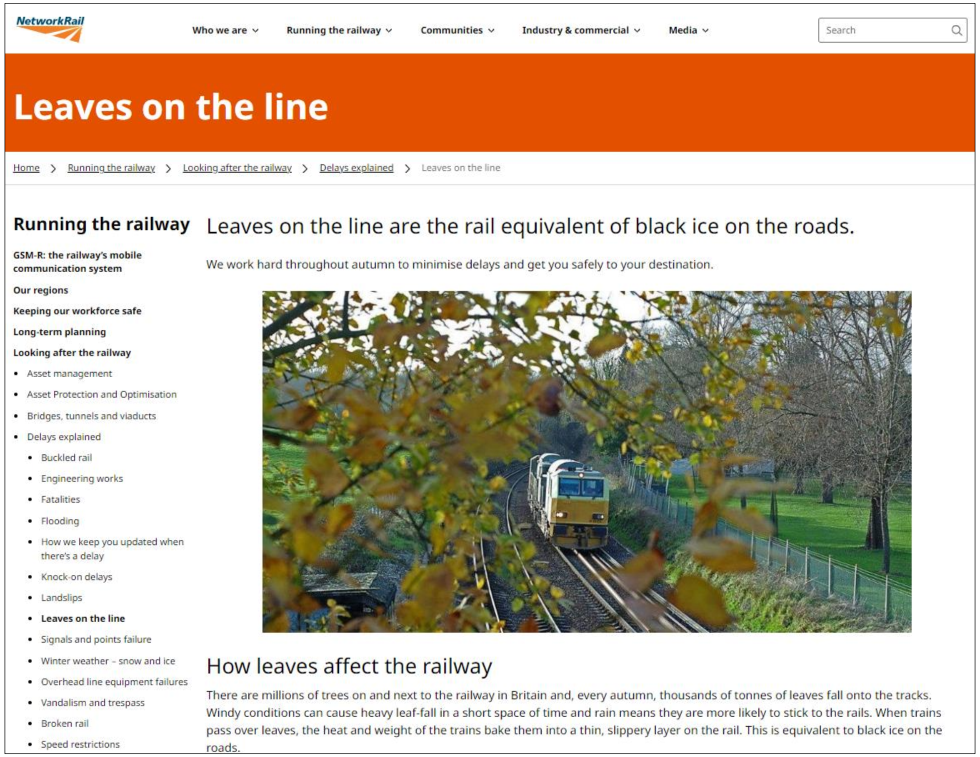
3.2.3 Media and opinion formers

Good media relations are essential to ensuring that passengers and the general public see a balanced account of the autumn problem in the press and social media. The press and opinion formers need to receive well-informed information through press releases, social media and internet. Site visits for opinion informers should also be considered.



3.3 Training and competence

The competence of staff undertaking safety critical activities on rail contamination is vital. This includes:

- Train driving – braking / acceleration technique, operation of trainborne sanders, recognising potential low adhesion conditions, route knowledge of high-risk sites;
- Drivers reporting low adhesion conditions, subsequent warnings to other drivers by signallers and conducting controlled test stops;
- Identification of low adhesion conditions and high-risk sites;
- Implementation and lifting of special operating restrictions;
- Inspection of contaminated rails, including swab sampling, contaminant identification and measurement;
- Inspection of contaminated and damaged wheels;
- Manual railhead treatment and cleaning processes;
- Maintaining and operating sanding, scrubbing, water jetting and railhead treatment equipment;
- Replenishment and maintenance of Traction Gel Applicators (TGAs) – one user found that Traction Gel needs to be stirred every week to avoid it setting in the hopper;
- Filling on train sanders, testing the pipework, and ensuring that they will work when commanded by the WSP – pushing the solebar test button is not enough;
- Removing fallen tree debris from the trackside to avoid causing localised low adhesion – a factor at Salisbury;
- The observation of track circuit operation.

This section discusses training and competence across four groups of staff and, the last, is pan-industry:

- Drivers;
- Signallers;
- Control Office staff;
- Those analysing data recorders;
- The Weather Learning Hub.

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3.3.1 Drivers

Experience has shown that adopting a cautious braking technique as part of a Professional Driving Policy (PDP) can contribute significantly to reducing adhesion-related incidents. Train operators 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; Trade Associations being a good mechanism for this.

PDPs have been at the forefront of SPAD management in recent times and are 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 and use, any trailing vehicles, along with isolated brakes, non-operational equipment and anything else which could otherwise impact on braking techniques. Additional running brake tests should be carried out to get the feel of the train's brakes. New or cascaded rolling stock may not perform the same as the outgoing stock under low adhesion on a given route, so safety and operations managers need to understand the impact as part of fleet introduction (RSSB R&D project T1221), and check driving policies fully exploit the train's capability (RSSB R&D project T1305).

> **Operational Performance – How Is Autumn Worse?**
> About half of time lost during deceleration on the Cross-City Line (Class 323s) in Autumn 2019 was due to the differences in braking practices (not demanding enough braking). Driving practices were also implicated in the slight losses during the acceleration and cruising phases. One of the key recommendations for industry was to ***"consider a change to driving policy to make the most of the train's capabilities to make the most of all available adhesion"***.
> RSSB R&D project T1181 and COF-LAD

- Formation – the number of vehicles in the train affects 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 A7). The braking performance of loaded freight vehicles will differ from the same vehicles when they are running empty. Therefore, drivers should be provided with braking instructions tailored to the fleets they drive rather than just the 'standard' instructions.
- The route – drivers should maintain comprehensive route knowledge including known low adhesion areas and 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 that are likely to be subject to low adhesion and regular attention paid to the Weekly Operating Notice (WON) for any updates. When rail adhesion is found to be worse than would be expected for the location and environmental conditions, drivers should report the location in accordance with GERT8000-TW1 (section 3.6.1). 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 know how and when to conduct a controlled test stop when requested by the signaller (section 3.6.1). Drivers should also look for changing conditions whilst driving.
- Braking – braking performance varies between fleets, even similar fleets. Furthermore, it should not be assumed that the braking performance of any train will be the same on every journey or at any given point. 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 (RSSB R&D project T1305). Where fitted, WSP should be allowed to do its 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.
- Approaching stopping points – care is required on the final approach to a stop aspect or any other stopping point 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, diligence, communication, decision making and action, co-operation and working with others, workload management, and self-management. More information is available from RSSB.

In 2019, RSSB explored the information needed by drivers to help them manage low adhesion (RSSB R&D project T1156). The toolkit that was developed presented six key principles for making information usable to drivers (timeliness; accuracy; relevance; simplicity; availability; and, memorability). Six key messages were identified to enhance driver confidence:

- Details about how on-board systems function and the best driving and braking technique for the system to achieve the maximum benefit;
- On-board systems (such as WSP and sanding equipment) are reliable and can be trusted if operated correctly;
- The importance of taking a moment to prepare when driving different units;
- Explaining that emergency braking shows positive, decisive action;
- Reinforcing the risks of early braking and low-speed slides;
- Emphasising that railhead conditions have improved nationally in recent years.

Experience of driving in low adhesion conditions

Drivers can gain an appreciation of what it is like to drive in low adhesion conditions by spending time on driving cab simulators (appendix A1.1.1). Ideally, drivers should have access if training during the Autumn cannot be undertaken or poses unacceptable risks.

Inexperienced drivers typically have additional simulator training and are accompanied by a driver assessor or mentor on their first run during Autumn; those with previous adhesion problems often get more simulator training.

Drivers that are trained in the spring or summer may miss out on 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.

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, and how well their drivers have been supported:

- 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

Training and assessment of signallers should include specific modules for managing train operations during the Autumn. Signallers need to take action when problems arise with track circuits or railhead conditions are worse than expected. This will include requesting cautioning drivers and controlled test stops (section 3.6.1).

Historically, signallers 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. Nowadays, GSM-R train radios enable signallers to caution drivers by arranging berth-triggered broadcasts to play a pre-recorded message to them when the train enters the affected area (GERT8000-TW1). The signaller then clears the signal once the warning has been acknowledged by the driver. **Lower SPAD risk and 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.

Edition 7, May 2024

3.3.3 Control Office staff

Control office staff are vital to the successful and safe management of the autumn period, especially those in the Adhesion Control Centres (section 3.5.3). Whilst balancing the needs of delivering a service for passenger and freight trains, they will manage:

- When to implement and remove operational restrictions;
- Railhead Treatment Train (RHTT) operation in real-time;
- Possession conflicts;
- Access arrangements for the response teams.

They also need to communicate to drivers:

- Daily or updated forecast from Network Rail control to the train operator's control;
- Adhesion information, such as missed treatment sites, sent to drivers electronically or via booking on points, e.g. screens and / or Late Notice Cases;
- Information noted by drivers when booking on.

The mechanism for this will vary throughout the industry, but critical things are for control staff to:

- Know what rules, instructions and other processes apply for any given weather scenario;
- Have ready access to the information they need to make the right decision;
- Clearly communicate information at each interface (to avoid important details being missed);
- Record what they have done.

All this is not possible without information on how the service is performing and weather forecasts. Training on the interpretation of forecasts and data provided by remote monitoring systems is vital for ensuring best use of the information. As is training on collating accurate information to inform post-season reviews and planning next season's mitigations.

3.3.4 Those analysing data recorder evidence

On Train Data Recorder (OTDR) 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 those involved (appendix A1.4.1).

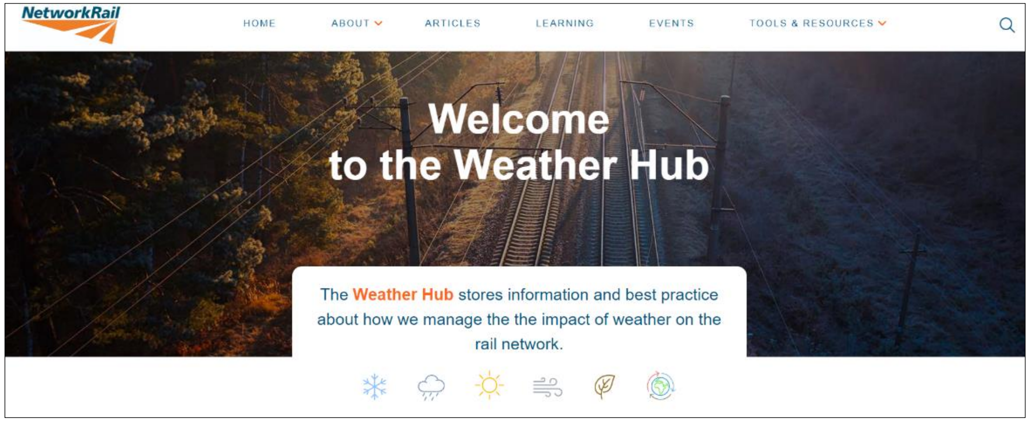
3.3.5 The Weather Learning Hub

The Weather Academy is part of an initiative developed by Network Rail to promote organisational change to reduce risk during extreme weather, as put forward by the Weather Advisory Task Force (WATF) expert review instigated following the Carmont derailment which tragically resulted in the loss of three lives and injured six people.

> **Weather Advisory Task Force – Recommendation 5**
> *Network Rail needs to build its professional competences in meteorology, hydrology, and climate change so its staff can act as intelligent users of science and services across all its functions. The WATF proposes the creation of an 'Academy' which will act to transform the culture of decision making in Network Rail.*

Among several activities launched by the Weather Academy, the Weather Learning Hub is a publicly accessible website that allows Network Rail to share weather-related best practices and insights with both internal teams as well as external stakeholders, including train or freight operating companies and industry partners.

The site provides access to a wide range of material from e-learning and podcasts to weather related articles and event reports. The hub is regularly updated and is the 'go-to' place for learning on the weather and the railway, the Weather Academy, and to register for upcoming events that they host.



3.4 Timetabling and diagramming

This section discusses three factors that minimise the effects of low adhesion through timetabling and diagramming:

- Short trains;
- Autumn timetable;
- Operating restrictions.

3.4.1 Short trains

Experience has shown that short trains are generally more susceptible to low adhesion braking problems (appendix A7). Analysis shows that over 80% of adhesion related 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. RSSB's "Policy Guidance for Low Adhesion Driving—Passenger Operations" (RSSB R&D project T1221) offers the following advice to them: *"Take a moment to prepare when moving between trains that require a different driving style. Check the train's formation remembering that shorter trains can be more prone to wheel slip and remind yourself of the onboard adhesion systems that are available and how to get the most from them".*

Improved Wheel-Rail Adhesion Calculation

RSSB research with the University of Huddersfield estimated the adhesion at each wheelset to get a better understanding of the impact of cleaning (conditioning) after each wheel passage and sanding effects.

"…It is expected that the sanding effect will reduce as more wheelsets pass over the sand, so the further the wheelset from the sander the lower the benefit from the sand. On the other hand the cleaning effect will increase as more wheelsets pass…"

RSSB R&D project COF-UOH-63

If possible, short trains should be worked in multiple with other short trains, thus providing additional wheelsets to help condition the rails and improve overall traction and braking performance. Similar consideration should be given to articulated trains which have fewer wheelsets than conventional trains.

3.4.2 Autumn timetable

Planning an operational timetable for the autumn period restricts speeds in areas prone to low adhesion. This increases the reliability of train services, albeit at the expense of increasing certain point-to-point train running times. This 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, thereby reducing the energy to be absorbed during braking, requiring less braking effort, and making less demand on 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 created by adding a few minutes here and there: connections need to be maintained; turn-round times must be sufficient; contract / concession agreement deviations may be required from funders; etc. Most importantly, timetable alterations must be publicised well in advance, otherwise passengers will turn up for trains that may have already departed.

3.4.3 Operating restrictions

Operational requirements are dictated by the Rule book, National Operational Instructions and Special Box Instructions in that order of priority. This permits operating restrictions to be implemented if adhesion related incidents occur. For example:

- High-risk sites with potential for wrong side failures of track circuits should have special working arrangements (NR/L2/OPS/095 "High Risk Sites for Wrong Side Track Circuit Failures in Leaf Fall Areas and for Low Rail Adhesion" and RIS-3708-TOM "Arrangements Concerning the Non-Operation of Track Circuits During the Leaf Fall Contamination Period");
- Giving freight trains a clear path;
- Closing level crossing gates near to sites prone to platform overruns or signals being passed at danger prior to a train approaching.

The process for identifying any necessary operating restrictions should be included in the joint Railhead Adhesion Management Plan (RAMP) (section 3.1).

Edition 7, May 2024

3.5 Managing adhesion information

Today's technology means we are faced with ever increasing volumes of data at our finger tips. As long as it can be easily turned into actionable information, this data is valuable for identifying when and where low adhesion may be a problem, and for deciding what measures to apply.

This section considers:

- Gathering data;
- Disseminating information;
- Adhesion Control Centres;
- Leaf fall forecasting / weather reports;
- Train-based low adhesion identification / warning systems;
- Identification and marking low adhesion sites.

3.5.1 Gathering data

Sources of data include:

- **Low adhesion sites** – those sites where vehicles regularly experience problems based on previous history and local knowledge;
- **Weather conditions** – the weather 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 provide up-to-date knowledge of local conditions such as ambient temperature, humidity, wind speed and dew point;
- **Trains** – an effective way of obtaining real-time reports and post-season analysis of such sites is from train-based systems (section 3.5.5), which can provide a map of such sites together with the severity of the conditions and how the site is changing over time;
- **Adhesion related incident data** – locations where adhesion related incidents have occurred: signals passed at danger; stations platform overruns; collisions; locations where trains have failed to be detected by track circuits; the adhesion index (section 3.5.4); and, where accelerating away from a stand is a problem. In 2023, Network

Edition 7, May 2024

Rail's National Weather Team introduced their new Weather Resilience App (WRAPP) to facilitate this (section A1.1.2);

- **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. GPS linked with on-train systems can also provide very granular levels of detail on low adhesion sites for both braking and accelerating (section 3.5.5);
- **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 train-based systems (section 3.5.5) for example, can further aid vegetation management (section 4.2.1).
- **Human input** – reports from drivers, signallers and infrastructure maintainers.

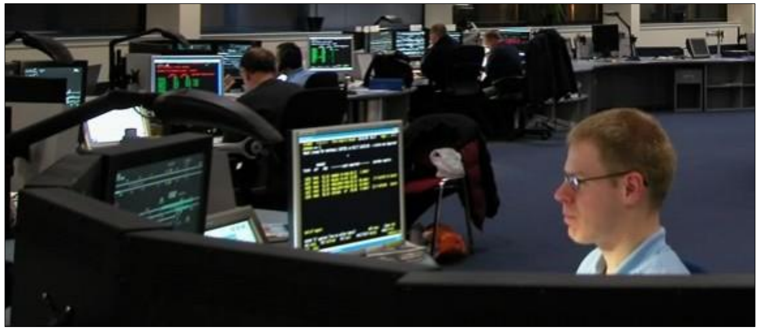
3.5.2 Disseminating information

Once the data has been turned into actionable information, it needs to be disseminated 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 in response to emerging conditions as well as proactive;
- **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 and directing front line staff;
- **Management** – to maintain their awareness of current conditions.

3.5.3 Adhesion Control Centres

During the leaf fall period, Network Rail deploys additional staff into Control Offices to assist with application of control measures and data collection. 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 / 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 response teams to locations requiring immediate attention.

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 a system called Rail360 which is linked to their Fleet Asset Management System (FAMS) and are the first line of reporting for all matters.

3.5.4 Leaf fall forecasting / weather reports

Leaf fall prediction and weather forecasting services are provided by the Network Rail Weather Service from MetDesk.

Network Rail National Operating Procedure NR/L3/OPS/045/3.17 “Weather Arrangements” requires the weather forecast provider to supply a forecast of adhesion conditions during the autumn period. This is provided as the ‘adhesion index’ described below which takes into account precipitation as well as leaf fall.

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

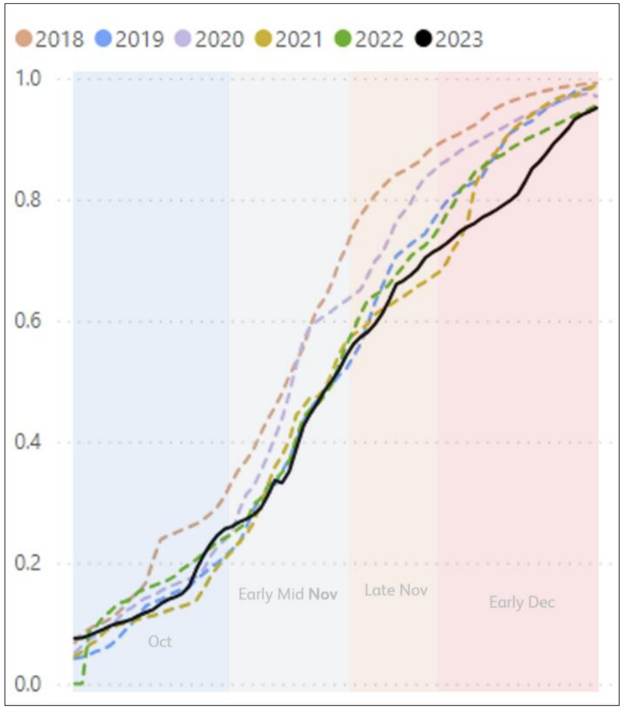
Edition 7, May 2024

Managing Low Adhesion

SCSG

Amongst other things, these forecasts can advise:

- When the leaf fall season may begin in earnest (see adjacent graph showing leaf falls over recent years);
- Impending risk days;
- When the risks are subsiding towards the end of the season;
- General weather patterns and approaching events that might lead to significant problems, for example high winds.

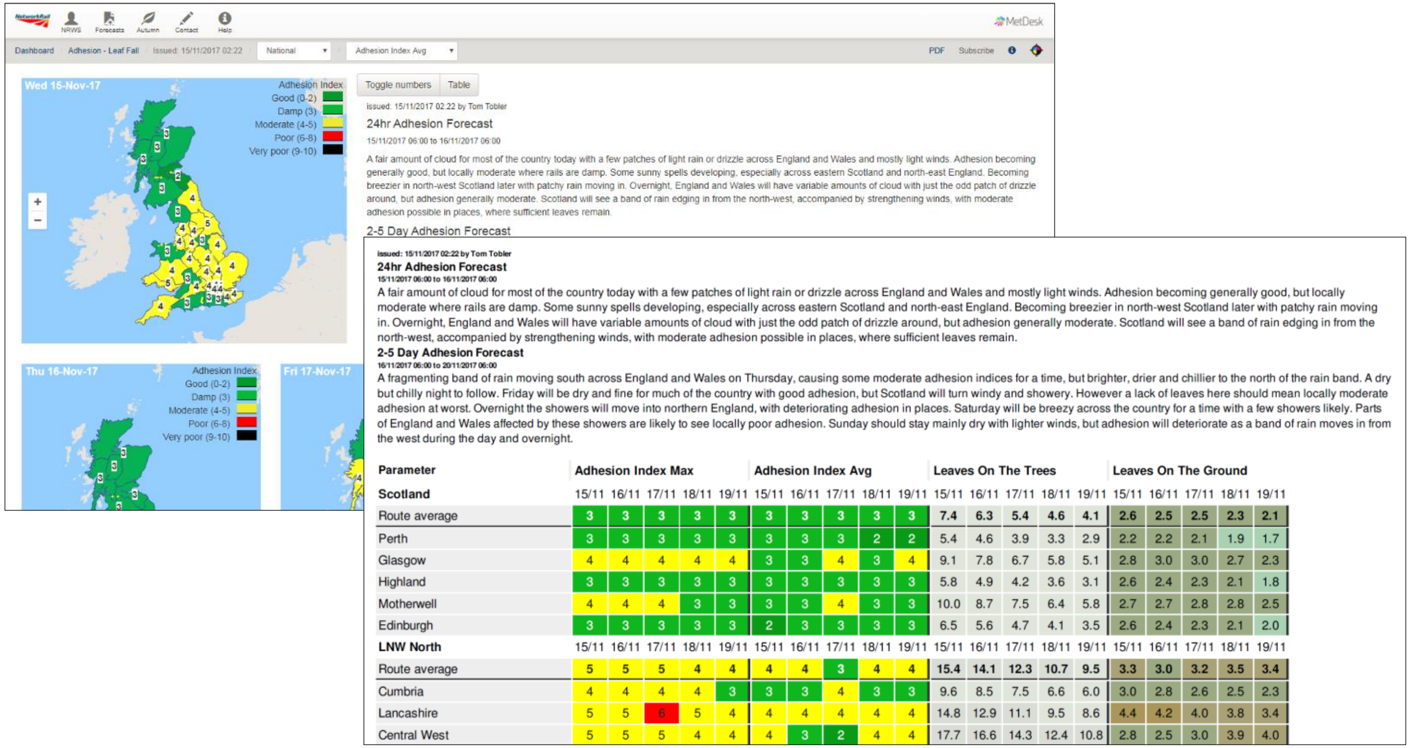


During the autumn period, a five-day adhesion forecast is provided containing a summary map of the country with smaller maps showing the long-term outlook. These are colour coded to signify levels of severity, and are uploaded twice per day. In addition, maps are available for each Network Rail Route.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

Edition 7, May 2024

Managing Low Adhesion

The images 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.



issued: 15/11/2017 02:22 by Tom Tobler

24hr Adhesion Forecast

15/11/2017 06:00 to 16/11/2017 06:00

A fair amount of cloud for most of the country today with a few patches of light rain or drizzle across England and Wales and mostly light winds. Adhesion becoming generally good, but locally moderate where rails are damp. Some sunny spells developing, especially across eastern Scotland and north-east England. Becoming breezier in north-west Scotland later with patchy rain moving in. Overnight, England and Wales will have variable amounts of cloud with just the odd patch of drizzle around, but adhesion generally moderate. Scotland will see a band of rain edging in from the north-west, accompanied by strengthening winds, with moderate adhesion possible in places, where sufficient leaves remain.

2-5 Day Adhesion Forecast

16/11/2017 06:00 to 20/11/2017 06:00

A fragmenting band of rain moving south across England and Wales on Thursday, causing some moderate adhesion indices for a time, but brighter, drier and chillier to the north of the rain band. A dry but chilly night to follow. Friday will be dry and fine for much of the country with good adhesion, but Scotland will turn windy and showery. However a lack of leaves here should mean locally moderate adhesion at worst. Overnight the showers will move into northern England, with deteriorating adhesion in places. Saturday will be breezy across the country for a time with a few showers likely. Parts of England and Wales affected by these showers are likely to see locally poor adhesion. Sunday should stay mainly dry with lighter winds, but adhesion will deteriorate as a band of rain moves in from the west during the day and overnight.

Parameter	Adhesion Index Max					Adhesion Index Avg					Leaves On The Trees					Leaves On The Ground				
Scotland	15/11	16/11	17/11	18/11	19/11	15/11	16/11	17/11	18/11	19/11	15/11	16/11	17/11	18/11	19/11	15/11	16/11	17/11	18/11	19/11
Route average	3	3	3	3	3	3	3	3	3	3	7.4	6.3	5.4	4.6	4.1	2.6	2.5	2.5	2.3	2.1
Perth	3	3	3	3	3	3	3	3	2	2	5.4	4.6	3.9	3.3	2.9	2.2	2.2	2.1	1.9	1.7
Glasgow	4	4	4	4	4	3	3	4	3	4	9.1	7.8	6.7	5.8	5.1	2.8	3.0	3.0	2.7	2.3
Highland	3	3	3	3	3	3	3	3	3	3	5.8	4.9	4.2	3.6	3.1	2.6	2.4	2.3	2.1	1.8
Motherwell	4	4	4	3	3	3	3	4	3	3	10.0	8.7	7.5	6.4	5.8	2.7	2.7	2.8	2.8	2.5
Edinburgh	3	3	3	3	3	2	3	3	3	3	6.5	5.6	4.7	4.1	3.5	2.6	2.4	2.3	2.1	2.0
LNW North	15/11	16/11	17/11	18/11	19/11	15/11	16/11	17/11	18/11	19/11	15/11	16/11	17/11	18/11	19/11	15/11	16/11	17/11	18/11	19/11
Route average	5	5	5	4	4	4	4	3	4	4	15.4	14.1	12.3	10.7	9.5	3.3	3.0	3.2	3.5	3.4
Cumbria	4	4	4	4	3	3	3	4	3	3	9.6	8.5	7.5	6.6	6.0	3.0	2.8	2.6	2.5	2.3
Lancashire	5	5	6	5	4	4	4	4	4	4	14.8	12.9	11.1	9.5	8.6	4.4	4.2	4.0	3.8	3.4
Central West	5	5	5	4	4	4	3	2	4	4	17.7	16.6	14.3	12.4	10.8	2.8	2.5	3.0	3.9	4.0

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.

The industry also uses Met Office weather alerts to inform decisions.

Edition 7, May 2024

3.5.5 Train-based low adhesion identification / warning systems

An effective way of gaining immediate information on low adhesion conditions is to use service trains to provide data on wheel spin / slide to a central computer in real-time. Amongst other things, the information can then be used:

- In real-time to give advanced warning to drivers of poor railhead conditions;
- In real-time by Adhesion Control Centres to direct application of control measures;
- Retrospectively, during post-season reviews to determine where future vegetation control is required.

Understanding leaf effects on low adhesion

An RSSB / EPSRC funded PhD studentship in collaboration with the Universities of Sheffield and Leeds, developed a unique, cutting-edge low adhesion forecasting model, that can significantly improve our understanding of low adhesion risk and better target risk mitigation measures, such as railhead treatment. When combined with wheel slip data (from train operators or directly from remote OTDRs) the model, which has been validated against low adhesion reported by drivers / infrastructure staff, provides what is set to be the most comprehensive and accurate low adhesion forecast yet.

RSSB R&D project COF-ITR-03

Such systems include:

- Low Adhesion Warning Systems such as: Notus, Seasonal Intelligence Platform, and Trimble Nexala Solutions (section 5.5.3);
- Forward Facing CCTV (FFCCTV) (section 5.5.2);
- On-Train Data Recorders (OTDR) (section 5.5.1).

3.5.6 Identification and management of high-risk sites

Vulnerable locations are classed as high-risk sites either for low adhesion reasons or because of track circuit operating issues. These sites must be identified and details communicated to:

- Train operators – whose drivers need to take appropriate precautions (section 3.3.1);
- Signallers – who need to be aware of these locations to implement rules and procedures (section 3.3.2)
- Control Office staff – for similar reasons (section 3.3.3);

- Infrastructure maintainer / manager – to plan and implement vegetation management and remedial treatment programmes (section 4).

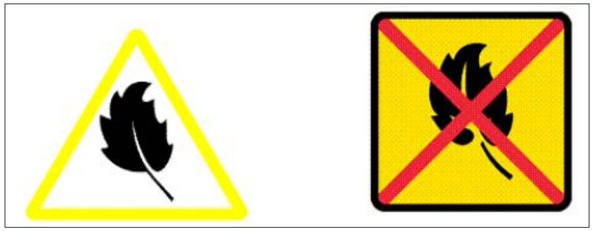
Network Rail standard NR/L3/OPS/021/01 “Autumn Management” mandates how Network Rail prepares, manages and responds to risks arising from autumn weather related hazards to minimise the risk of safety incidents. As part of this, the standard defines how high-risk sites are to identified and managed.

Sites are currently classed as ‘high-risk’ based on the following criteria (in future, modern technology could augment this with WSP alerts and similar data sources to identify where trains are slipping and then factor in the consequences of a slide occurring):

- Two SPADs or four station overruns in the last three years;
- Score of 26 or more from the Leaf Fall Risk Assessment NR/L2/OTK/5201/F3076;
- Two or more WSTCFs in the last three leaf fall seasons.

Once high-risk sites have been identified, Network Rail is responsible for:

- Compiling and sharing a list with relevant train / freight operators for agreement;
- Risk assessing all high-risk sites using the adhesion risk matrix in NR/L2/OPS/095/F01;
- With other affected Duty Holders, creating mitigation plans to manage the risk to ALARP for identified sites (section 3.1);
- Maintaining the list for the duration of the autumn season at Route and national level;
- Putting signage in place to warn drivers (adjacent) - Railway Group Standard GIRT7033 “Lineside Operational Signs – Product Requirements” applies;



- Agreeing a removal plan with relevant operators;
- Updating the relevant Network Rail Sectional Appendix prior to the autumn season.

However, the situation can often change during the season:

- New high-risk sites may arise;
- Some existing high-risk sites may cease to be a problem. However, this could be because the remedial measures are being effective. It may therefore not be appropriate to stop the measures to avoid resurrecting the problems.

The process for communicating details of high-risk sites must therefore be dynamic and react to these changes.

Train / freight operators may also have a list of 'sites to be aware of' which aren't in the formal list, but which are briefed out for awareness particularly for new drivers. These sites are based on driver feedback.

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 (section 3.3.1) and signallers play a vital role in advising others (section 3.3.2). Once these new conditions have been reported, there may be a need to implement mitigations 'on the ground'.

This section considers:

- Reporting and managing low adhesion;
- Reacting to emerging conditions;
- Line proving;
- Responding to non-delivery of control measures on the day.

Edition 7, May 2024

3.6.1 Reporting and managing low adhesion

Colloquially termed 'TIGER' (Track Is...), the Rule Book (GERT8000-TW1) defines adhesion conditions as follows:

Good	Rail adhesion conditions are good
Expected	Rail adhesion is no worse than would be expected for the location and environmental conditions
Reportable	Rail adhesion is worse than would be expected for the location and environmental conditions

Drivers must:

- Follow their PDP for low rail adhesion at locations where they expect to experience 'expected' adhesion levels;
- Tell the signaller immediately if they experience 'reportable' rail adhesion levels.

On receiving a report of low adhesion from a driver, the signaller must then take action as per the Rule Book / Operating Instructions/ Special Box Instructions, such as:

Locations where conditions apply	**Action to be taken**
Approach to a stop signal or an End of Authority (EoA)	Arrange for the driver of each train to be told about the circumstances unless the signal is showing a proceed aspect or an MA has been issued beyond the EoA
Controlled level crossing within the overlap of a signal or EoA	Close the crossing to road traffic before each train approaches
AHBC level crossing	Select the non-stopping mode (where provided)
Approach to a platform	Arrange for the driver of each train booked to call to be told about the circumstances
Dead-end platform	Arrange, if possible, for the platform to be taken out of use

Edition 7, May 2024

GSM-R train radio enables discrete warnings to individual trains or general broadcasts to all drivers in an area. The 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 reportable 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. However, GSM-R cautioning on the move is only permitted when:

- The train is running on green signals;
- The train is on the same panel as the stop signal which controls the affected section when the driver acknowledges the berth-triggered message, to avoid the risk of miscommunication between signallers.

GERT8000-TW1 requires signallers to arrange for a train to make a controlled test stop at the location concerned, if one of the following applies:

- The signaller has been told that the railhead has been inspected and nothing unusual has been found;
- The signaller has been told that the railhead has been inspected and improvement treatment carried out;
- At least 30 minutes have passed since the signaller was told about the 'reportable' rail adhesion level.

If possible, the controlled test stop should be performed by a similar type of train to that which reported the conditions; an incident involving a disc-braked short train should not be tested with a freight train. When told to make the controlled test stop, the driver must brake the train in the normal way for the environmental and rail adhesion conditions at the location, rather than the way used for 'reportable' rail adhesion levels.

If the driver reports that the rail adhesion level is still 'reportable', further controlled test stops will be required. Normal working must not resume until a controlled test stop has been carried out and the rail adhesion level is no longer considered as 'reportable'.

GERT8000-TW1 defines further requirements for the above process that must be followed.

Edition 7, May 2024

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 04:00hrs 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 (section 3.5.4) the extreme weather response process will be utilised. This may include additional:

- Staffing;
- Rail Head Treatment Train (RHTT) runs;
- Inspections at high-risk sites of low adhesion or of Wrong Side Track Circuit Failures (WSTSCFs).

Network Rail also hold national, weekly teleconference called the Tactical Adhesion Teleconference (TAT) during the autumn period.

3.6.3 Line proving

Line proving is a method of proving that the railway is working correctly with the normal operation of the train detection and signalling system. Line proving can be carried out with any train that can be relied upon to occupy track circuits.

Network Rail National Operating Procedure NR/L3/OPS/045/3.41 "Route and Line Proving Process" requires that:

- Where a line has been closed in excess of 48 hours, the Route Control shall make a decision about whether line proving is required;
- Where a route is closed for over 60 hours, line proving shall always be carried out;
- When making the decision to line prove, the Route Control shall consider:
    - The weather conditions during the time no trains were running over the line;
    - The period since the last service traversed the line;
    - Whether sweep trains have been used during the closure;

Edition 7, May 2024

- The last time the line was treated for low adhesion;
- The season and therefore likelihood of contamination that could affect the normal operation of the signalling equipment;
- The risk of trespass, vandalism or theft;
- Continuity of the traction power system.

▶ Where line proving is required, it shall be completed on each running line where there are multiple lines.

3.6.4 Responding to non-delivery of control measures ‘on the day’

The Railhead Adhesion Management Plan (RAMP) defines which control measures are to be delivered, the lead Duty Holder responsible for delivery, and when they are to be delivered (section 3.1). Inevitably there will be times when control measures are not delivered according to the RAMP. Corrective action is then required to reduce low adhesion risk for train operations to acceptable levels.

When control measures fail ‘on the day’, lead Duty Holders need to carry out the process described in the RAMP for identifying other risk mitigations and agree the outcome jointly with other affected Duty Holders. This means:

▶ Quickly identifying that a planned control measure has failed ‘on the day’**;**
▶ In extreme conditions, considering additional resources required;
▶ Considering delivering other control measures to manage the risk;
▶ Recording the conclusions reached.

Edition 7, May 2024

3.7 Performance monitoring

Weekly monitoring

During autumn, Network Rail hold a national, weekly teleconference called the Tactical Adhesion Teleconference (TAT) which brings together representatives from Network Rail's National Adhesion Team, Seasons Delivery Managers / Specialists and train / freight representatives and other relevant industry parties. The TAT aims to identify emerging problems and timetable issues by reviewing such things as:

- Weather and rate of leaf drop;
- Safety KPIs: station overruns, WSTCFs and SPADs;
- Reports of low adhesion (ROLA);
- Train performance;
- Review of high-risk sites – adding / removing sites as per NR/L2/OPS/095 "High Risk Sites for Wrong Side Track Circuit Failures in Leaf Fall Areas and for Low Rail Adhesion";
- Review of treatment effectiveness.

End of season review

Network Rail Routes and train / freight operators should also review their performance at the end of season by 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 treatment trains ran against the booked plan?
- Where used, how effective was the autumn timetable?
- 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.

Edition 7, May 2024

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Annual industry review

Each year, Network Rail is required under its Network Code to convene a 'National Seasons Review'. The 'National Adhesion Review' takes place in spring and provides an opportunity for the industry to come together to review adhesion performance. The objectives 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;
- Learn about R&D projects that aim to mitigate the impact of low adhesion in the years ahead;
- Learn from other railway administrations;
- Provide an opportunity for industry to meet with suppliers;
- Inform seasonal management skills across all Britain's rail modes.

4 Infrastructure measures

Managing low adhesion on the infrastructure involves:

- A long-term vegetation management strategy delivering planned, costed and prioritised programmes of work leading to a long-term position of a sustainable, steady state requiring minimal maintenance;
- A rigorous programme of proactive and reactive railhead treatments.

A range of measures are available to infrastructure managers to complement those undertaken by train / freight operators. The process involves:

- Identifying the locations subject to, or likely to be affected by, adhesion-related problems (section 3.5.6);
- Selecting the most appropriate treatment depending on the nature of the contaminant.

Treatment can be grouped into three types:

- Preventative methods – such as reducing the number of leaves at source and preventing leaves being blown on to the track and drawn into the slipstream of passing trains and into the wheel / rail interface;
- Cleaning methods – cleaning the railhead to enhance adhesion;
- Friction enhancement – adding friction modifiers such as sand.

Of these, the first is the most effective as it addresses the root cause, whilst the latter two keep things moving (or stopping) by addressing the immediate effects. This section describes these in the following sub-sections:

- Identifying low adhesion;
- Preventing contamination;
- Treating low adhesion;
- Other mitigations.

Edition 7, May 2024

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4.1 Identifying low adhesion

Identifying the locations subject to, or likely to be affected by, adhesion-related problems must be the first step in combating the effects of low adhesion. This section discusses three aspects of the process:

- Recognising contamination;
- Taking swab samples;
- Measuring adhesion levels;

4.1.1 Recognising contamination

Unless we know what form of contaminant is present, we cannot determine the most appropriate method of treatment. It is therefore essential those examining rails for contamination have knowledge of:

- The potential causes of low adhesion;
- The sources of them;
- Recognition of physical characteristics;
- 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 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 (section 4.1.2).

Remote inspection of the rail head

Subject to lighting and weather conditions, drones can capture images of the railhead and contamination closer to the time of the incident while keeping personnel off the track. The image of light leaf contamination below was taken by a drone >50m from the line, so its quality could be replicated on operational lines without traffic interruption or lineside working. The technology is being trialled in various NR regions. Forward-facing cameras are also being developed to assess contamination and would allow inspection soon after the incident. Drones must be operated by trained staff (NR/L3/OPS/251).

RSSB R&D project T1222

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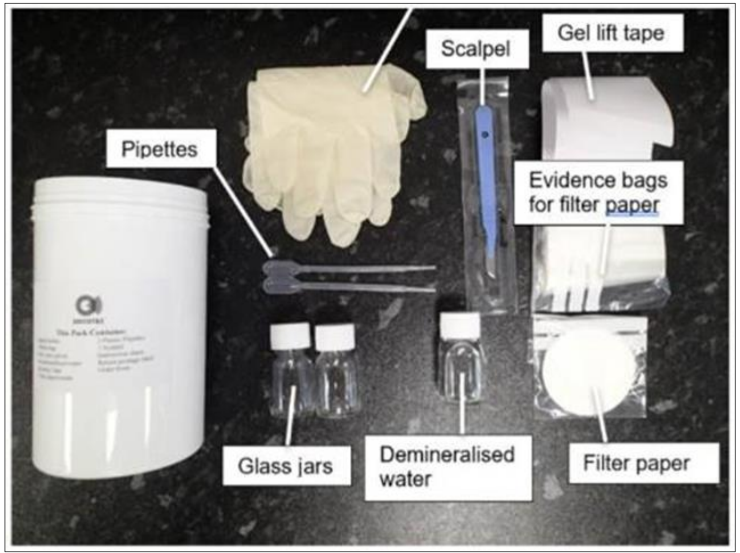
4.1.2 Taking swab samples

Network Rail National Operating Procedure NR/L3/OPS/045/3.36 "Signals Passed at Danger (SPAD) or Signals Passed at Red (SPAR)" requires swab samples of the railhead to be taken following Category A SPADs "*if any allegation has been made regarding loss of adhesion as a contributory factor to the incident*". NR/L3/OPS/045/4.07 "Taking Samples of Railhead Contamination" expands on this and requires sampling "*following any incident of collision, category A SPAD, station overrun or other incidents, where it is believed that the condition of the railhead may have been a contributory factor*".

If a serious incident has occurred and been reported to RAIB under their schedule 1.1 to 1.9, RAIB will take control of the site and evidence must not be compromised by other parties. In other circumstances, Network Rail will take swab samples in accordance NR/L3/OPS/045/4.07 and the following principles apply:

- Photographic evidence should be taken of the railhead and the context, i.e. the area in the up and down direction, to record the topography and tree species;
- A record should be taken of how the contamination varies between the up and down line, along with observations of wind and rain, and where the samples were taken;
- Swab samples can then be taken using portable kits to collect samples for a laboratory to later identify the contaminants present on the railhead. The instructions in NR/L3/OPS/045/4.07 should be followed to collect different types of samples as required:
    - Swabs for solid particulates are sterile filter paper that can stored in a plastic grip-seal bag;



- Liquid samples from the railhead obtained using a Pasteur pipette and placed into glass bottles provided, e.g. water, lubricant, and fuel;
- Tapings to lift fine organic material that is not well adhered to the railhead, can be stored in a plastic grip-seal bag;
- Layered railhead contamination scraped from the railhead should be wrapped in tin foil before placing in a plastic grip-seal bag (the tin foil is required to prevent hydrocarbons from the bag contaminating the sample).

- Care must be exercised when taking samples to ensure that only the running band of the rail is sampled as there will be large amounts of rust (often oil soaked) on the shoulders of the railhead. Contamination from other sources, such as grease on hands, should be kept away from the sample.
- 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. Swabs may also be taken from the two leading wheelsets of the vehicle(s) involved depending on how far they have had to travel following the incident.
- The chain of evidence should be preserved as explained in NR/L3/OPS/045/4.07.

4.1.3 Measuring adhesion levels

Sometimes it is necessary to measure railhead friction levels, for example after an operating incident or for R&D. There are a range of measuring tools and techniques which vary in their levels of accuracy. RSSB Guidance Note GMGN2642 “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 (extracted overleaf) recommends differing solutions depending on the requirement.

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	Train mounted methods	Vehicle borne tribometers	Portable tribometers	Laboratory test rigs	Service / test trains	Adhesion management methods
Incident investigation	No	No	1. Braked wheel tribometer 2. Static breakout friction 3. Skid resistance slider	No	1. OTMR 2. Brake test	No
Assess low adhesion treatment methods / rail cleaning	Yes	Yes	1. Braked wheel tribometer 2. Static breakout friction 3. Skid resistance slider	1. Twin disc test rig 2. Pin on disc machine 3. Full-scale wheel-on-rail rig	1. OTMR 2. Brake test 3. Modified service or test train (load measuring wheels or strain gauged axles)	No
Network adhesion status	Yes	No	No	No	1. TMS / WSP data 2. Modified service train (strain gauged axles)	Yes
Identify low adhesion sites	Yes	Yes	No	No	1. TMS / WSP data 2. Modified service train (strain gauged axles)	Yes
Check adhesion levels for test purposes (see 2.3.2)	Yes	Yes	1. Braked wheel tribometer 2. Static breakout friction 3. Skid resistance slider	No	1. Brake test 2. OTMR 3. Test train (load measuring wheels)	No
Check adhesion levels for driver training	No	No	1. Static breakout friction	No	1. Brake test distance to stop / deceleration	No
Laboratory investigations	No	No	1. Skid resistance slider 2. Static breakout friction	1. Twin disc test rig 2. Pin on disc machine 3. Full-scale wheel-on-rail rig	No	No
Product testing	Yes	Yes	1. Braked wheel tribometer 2. Skid resistance slider 3. Static breakout friction	1. Twin disc test rig 2. Pin on disc machine 3. Full-scale wheel-on-rail rig	1. Brake test 2. OTMR	No

A recent addition to available portable tribometers is from Rivelin Rail. It magnetically clamps to the railhead and uses an ER8 steel wheel to measure the friction coefficient over a 300mm length. It is simple to operate, weighs approximately 3kg and measurements can be taken in 60 seconds. The average friction coefficient is displayed on a screen and raw data can be saved to a memory card. Results can be used to quantify the extent of low adhesion and assess the effectiveness of railhead cleaning / treatment methods. The tribometer has been endorsed by the ARG as a tool to support the test process recommended in appendix A2.

4.2 Preventing contamination

> **RAIB report 12/2023 on Salisbury (para 147)**
> *No action to manage the vegetation had been taken between 2018 and 2021 and video footage shows that vegetation continued to grow on the main lines approaching Salisbury Tunnel Junction between 2019 and 2021.*

The risk arising from contamination needs to managed at all locations, as a location that is not yet a problem could be a problem in a few years' time if it's not managed. Vegetation, if left unchecked, will become an increasing problem year-on-year. As it is not usually possible to complete all that is required in one year, a sustainable lineside management strategy should be adopted as trees generally have many years of growth left. The size of the vegetation canopy grows and the cut back of vegetation needs to exceed the rate of growth in problematic locations.

This section discusses two aspects of the process:

- Vegetation management;
- Vegetation surveys.

Edition 7, May 2024

4.2.1 Vegetation Management

Effective vegetation management addresses the leaf fall low adhesion problem at source. 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:

LU report on Piccadilly Line wheel flats, 2016 (Executive Summary)

The service losses experienced during leaf-fall 2016, following similar losses in 2015, were due to low wheel-rail adhesion caused by a failure to control lineside vegetation… The service losses due to wheel flats in 2015 and 2016 have amounted to £20 million in Lost Customer Hours, and additional depot costs for remedial attention.

- 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;
- Trees or branches falling on the line and being struck by passing trains;
- Fire risk from dead material lineside, especially dead leaves and grass in cable-runs;
- Health risks from invasive species (both to staff and public).

Network Rail has implemented NR/L2/TRK/5201 "Lineside vegetation management manual", a management process for delivering an integrated autumn programme of vegetation management. Key requirements are:

- Reviewing vegetation locations for high-risks to include in seasonal management plans;
- Undertaking all inspections at a specified minimum frequency;
- Reviewing the plan and associated frequencies of inspection annually to assess if the frequency of inspection is sufficient to control tree risk;
- Conducting vegetation surveys to assess the severity of leaf fall expected during the autumn period on operational lines for each eighth of a mile section (section 4.2.2).

Managing Low Adhesion

SCSG

Habitat assessment and biodiversity surveys are carried out prior to undertaking vegetation management to establish the required course of action.

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.

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.

> **Valuing nature – a railway for people and wildlife… (foreword)**
>
> Firstly, and foremost, we must **value line side 'vegetation' as an asset**, not a liability. We need the right vegetation in the right place, reflecting a 'balanced scorecard' which optimises the need for a safe and reliable railway with positive environmental outcomes. The goal should be to give lineside vegetation the same weight as other performance assets such as track and signalling. Sending this message to senior managers would have an immediate and positive effect.
>
> © Crown copyright, The Varley Review, 2018

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.

Edition 7, May 2024

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, whilst appendix A3 provides 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) (appendix A1.2.1). 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 A1.2.2) and removing dead leaves (appendix A1.2.3).

4.2.2 Vegetation Surveys

Infrastructure based control measures cannot be effectively targeted until the vulnerable routes and locations have been identified.

Under NR/L2/TRK/5201 “Lineside vegetation management manual”, Network Rail conduct vegetation surveys to assess the severity of leaf fall expected during the autumn period on operational lines for each eighth of a mile section, recording the results on NR/L2/OTK/5201/F3076 “Leaf fall risk assessment”. The tree species, density, distance from rail, and topography are among the factors considered to arrive at a risk score. Remedial work is carried out when the score exceeds a specified limit and the scores also allow high-risk sites to be built into treatment plans.

On-site assessment of tree species is required and the individual must be able to identify a range of common tree species. An app / ID book or other supporting info can help with the decision if a species is not immediately identifiable.

Remote data capture information from aerial survey and video footage from trains are available to support management decisions, and mapping tools provide aerial imagery to assist with locating trees in relation to the railway. For example Automated Intelligent Video Review (AIVR) – developed by Bristol-based tech company One Big Circle – gathers a wide range of data from high-definition video around the railway.

Hi-Res Leaf Fall Monitoring

A PhD project led by the University of Birmingham developed a low-cost recording device that can measure leaf fall at a high spatial and temporal resolution, to enhance forecasting models and improve forecasting data.

Situated on the lineside and tested over two Autumns, the device was able to capture near infra-red hemispherical images of tree canopies, which were then processed to calculate the change in percentage leaf fall over time. The tests showed the device could be used at critical points along a route to measure the leaf fall of different species. Tests also showed it is possible to capture hemispherical images from a train at 125mph.

RSSB R&D project COF-E14-02

4.3 Treating low adhesion

The fundamental requirement is to prevent contamination in the first place, but this cannot always be achieved. Therefore, various treatments are deployed to remove or reduce the impact of 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.

The table below shows the different treatment methods / applications and where more information can be found in this manual. The remainder of this section discusses two aspects of railhead treatment:

- Water Jetting and Adhesion Modifier Treatments;
- Auditing effectiveness.

Method	Application					Proactive	Reactive	Appendix
	RHTT	RRV A1.2.6	Fixed A1.2.7	Service Trains	Hand			
Water jetting	✓					✓	✓	A1.2.4
Adhesion Modifier	✓	✓	✓	✓	A1.2.8	✓	hand	A1.2.5
Chemicals		✓	✓		✓	✓	✓	A1.2.10
Rail scrubbing		✓			✓		✓	A1.2.9

4.3.1 Water Jetting and Adhesion Modifier Treatments

Treatments

The main mitigation for low adhesion in GB is now high pressure water jetting prior to laying an adhesion modifier to improve friction (aka sandite of which examples include TG60 and Electrogel).

Tests conducted by ARUP for Network Rail in Autumn 2006 (appendix A7.5) found strong statistical evidence to show that water jetting combined with an adhesion modifier results in:

- Higher train braking rates than water jetting alone;
- More consistent train braking than water jetting alone.

Additional processes can be applied on a more localised basis, such as using static adhesion modifier laying equipment 'Traction Gel Applicators' (TGA), rail scrubbing equipment or hand applied adhesion modifier dispensers. Fixed equipment such as TGAs offer the benefit of continuous protection, as opposed to protection immediately after the passage of the Rail Head Treatment Train (RHTT).

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 adhesion modifier (appendix A1.2.4).

The objective of applying an adhesion modifier 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 build up of further contamination. A metal additive is included to aid the operation of track circuits to reduce risk from sand insulating the track circuit shunting (appendix A1.2.5).

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 laying adhesion modifier; the latter only being laid at specific sites, whereas water jetting occurs everywhere except points (unless permitted by the Route). To be effective at 60mph, high pressure water jetting (1500bar) is first used on the leading vehicle to clean the railhead and then adhesion modifier is laid behind from the rear vehicle on the cleaned railhead. A distinct advantage with this system is the ability to clean the rails and lay friction modifier at up to 60mph. This reduces the impact on line capacity and allows more flexible operation. Over the eleven-week autumn period, Network Rail's railhead treatment programme

Edition 7, May 2024

covers typically 1,000,000 miles to treat over 360,000 sites, delivering 270 million litres of water and 1,400,000 litres of adhesion modifier.

Scheduling

Despite 60mph operation, conflicts for track occupancy from service trains, engineering possessions and the RHTT / MPVs inevitably exist, not to mention 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**. Furthermore:

- The effects of engineering work on the treatment programme must be assessed in advance where pre-planned work is to be undertaken. Protecting RHTT paths has worked well on some routes, meaning that most small possessions will not affect the RHTT at all, and train planners provide slots for it when there is a more significant line block;
- Train / freight operators should be involved with planning treatment circuits; so they complement the train plan and RHTT paths can be inserted between service trains;
- Railway neighbours may complain about noise if the RHTT sits at one location for some time overnight given the antisocial times;
- As the RHTT runs regularly it is worth having a regulation policy for delays to the RHTT versus regular services.

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. See also section 3.6.4.

RAIB report 12/2023 on Salisbury (para 161)

Witness and documentary evidence shows that Network Rail's autumn mitigation measures, such as the railhead treatment programme, were given a lower priority than timetabled passenger services and engineering work. This meant that MPV treatment runs were frequently delayed or cancelled at weekends when much scheduled engineering work takes place.

RAIB report 15/2020 on Norwich Road (summary)

The investigation found that there was contamination of the railhead in the area caused by leaf-fall and atmospheric conditions. This contamination had not been removed because there were no railhead treatment trains on the Norwich to Sheringham line at weekends.

Edition 7, May 2024

Adjusting the duration of the treatment programme

Network Rail Business Process NR/L2/OPS/021 "Weather – Managing the Operational Risks" requires the following information to be gathered and assessed to establish whether the autumn railhead treatment programme should be extended, reduced or terminated early:

- Actual proposed dates for when the treatment trains are planned to be extended or cancelled;
- Confirmation that the general weather forecast for the proposed extension dates contains extreme weather warnings or, for early cessation, that the proposed cancellation date does not contain extreme weather warnings;
- Confirmation that there are or are no black or red leaf fall days forecast for the proposed dates;
- Confirmation that less than 90% of leaves are down (for extension), or more than 90% of leaves are down for the Autumn to date (for early cessation);
- Confirmation that more than 12 drivers' reports (for extension) or no more than 12 drivers' reports (for early cessation) of low rail adhesion per line of route or circuit have been reported in the week prior to the proposed extension or early cessation dates;
- Determine if there has been a decrease or increase in safety KPIs (Overruns, SPAD, WSTCF) reported in the week prior to the proposed extension dates to the 'peak' autumn weeks that are directly attributable to Autumn;
- Inspections by locally identified personnel have been carried out at high-risk sites of low rail adhesion and deemed to be either low risk or no contamination was found.

Operational precautions

As with the passenger and freight service trains, MPV and RHTT drivers need to briefed on the low adhesion forecast, and take appropriate precautions when driving over low adhesion, such as adjusting their braking technique accordingly. NR/L3/SCO/313 "On-Track Machines (OTMs) Driver and Operations Standards manual" refers.

Similarly, on-Track Plant (OTP) operators should assess the effects that poor / low adhesion has on braking performance particularly when working on gradients and cants. NR/L2/RMVP/0200 "Infrastructure Plant Manual" refers.

4.3.2 Auditing effectiveness

To provide assurance that effective railhead treatment is taking place, NR/L3/OPS/021/01 “Autumn Management” requires Network Rail to check the effectiveness of RHTT once per week at sites defined as high-risk for reasons of low rail adhesion or WSTCFs.

When auditing treatment, photographs of the railhead should be taken, and a verbal report of the audit made to Autumn / Route Operations Control, particularly if further actions are required to improve the condition of the railhead.

4.4 Other mitigations

Once the rails have been treated to mitigate the effect of low adhesion, there are still other precautionary measures that can be taken. This section discusses:

- The sighting of signals;
- Platform stopping points;
- Temporary Speed Restrictions.

4.4.1 The sighting of signals

Another safety risk posed by vegetation is obscuring signals from 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 (RSSB Rail Industry Standard RIS-0737-CCS “Signal Sighting Assessment Requirements”). This is not just a problem for the Autumn; it applies all year round and will become a particular problem in the Summer.

Whilst vegetation surveys (section 4.2.2) play an important part in gathering intelligence:

- Train / freight operators should also check for foliage obscuring signals as part of due diligence;
- Operators should programme cab rides in conjunction with representatives from Network Rail;
- Drivers should also be encouraged to report areas where the sighting of signals is a problem.

Footage from Forward Facing CCTV (FFCCTV) can also be invaluable (section 5.5.2).

4.4.2 Platform stopping points

Consideration should be given to where trains normally stop in relation to signals and buffer stops:

- The design of buffer stops on passenger lines must include the impact of known poor rail adhesion sites that would impact braking on the approach;
- Although it may not be possible, 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;
- If space permits, re-siting stop boards at stations should be considered where stopping due to low adhesion may be a problem and the boards are too close to the signal.

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.

Edition 7, May 2024

4.4.3 Temporary Speed Restrictions

Temporary Speed Restrictions (TSRs) can have a significant effect on train operation during the autumn period. Where adhesion is poor:

- Delays will occur when trains struggle to re-accelerate after a TSR;
- Trains may over-speed the TSR if braking difficulties are encountered on the approach.

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.

5 Rolling stock measures

This section describes rolling stock systems that can be used to mitigate the impact of low adhesion on safety and train performance by covering:

- Braking systems;
- Optimising braking performance;
- Improving train detection;
- Managing wheel flats;
- Improving information;
- Procuring new trains.

5.1 Braking systems

The key safety risk arising from low adhesion is the on-board braking systems being unable to stop trains in a controlled manner, increasing the risk of overruns and collisions. This section discusses three types of braking system:

- Pneumatic disc brakes (friction brakes);
- Electric brakes (aka rheostatic, dynamic or re-gen);
- Magnetic track brakes (MTB).

The first two of these are used across almost all GB mainline passenger rolling stock, whilst the MTB is scarcely used. Similarly, nearly all passenger rolling on the GB mainline railway is now disc braked. Tread brakes are still fitted to some older rolling stock such as Class 15X DMUs and, of course, remain the mainstay of the freight railway, as well as on London Underground because of space constraints. They are given some consideration in section 5.2.1.

Edition 7, May 2024

5.1.1 Pneumatic disc brakes

Pneumatic disc brakes are adopted by train manufacturers world-wide as the best choice of friction brake because they:

- Absorb more energy than tread brakes and so can operate at higher speeds;
- Respond quickly to driver demand;
- Provide consistent performance even in repetitive braking;
- Are lightweight and easier to replace during maintenance than the brake blocks used for tread brakes;
- Disc brake pads last longer than tread brake blocks, allowing maintenance intervals to be extended;
- Respond well when low adhesion brake control is implemented automatically.

However, there are some disadvantages:

- Disc brakes do not clean the wheel tread and thus remove contamination like tread brakes;
- The cost and effort of monitoring and replacing worn brake pads is a relatively high cost amongst rolling stock consumables. However, pad wear is greatly reduced on modern Electric Multiple Units (EMU)s with high levels of electric braking when compared against older EMUs that did not have this feature.

5.1.2 Electric brakes

Electric brakes use the train's kinetic energy to generate electricity in the traction motors. Modern electric trains can feed this electrical energy back into the overhead line or third rail supply. Modern AC overhead systems are more receptive to this return of electricity than DC systems, and approximately 30% of the energy can be returned for use by other electric trains or to the national supply. DC networks are less receptive and the returned electricity can only be used by other electric trains within the same electrical section. Diesel electric trains, like less advanced electric trains without regenerative braking, dissipate this electrical energy by passing it through on-board resistors (rheostats) converting the kinetic energy into heat.

While electric braking offers many advantages in terms of reduced mechanical wear, reduction in brake pad usage and a very consistent braking characteristic; there are some issues, including:

Managing Low Adhesion

SCSG

- Few GB trains have motors on every axle, therefore electrical braking must be applied at a higher rate on fewer axles than would be the case if braking were available on all axles. This increases the likelihood that wheels will slide when a driver brakes the train. For example an evenly loaded train with only 50% of its axles motored, would require twice the rail adhesion to sustain the same braking or retarding force than an equivalent friction brake design.
- Earlier versions of electric brakes had limitations in terms of the level of control that could be provided by the traction systems under low adhesion and slide conditions. Many of the first generation three phase AC powered EMUs (e.g. Class 465 and Class 323) had traction control systems which could be compromised by certain low adhesion conditions. Therefore, the overall low adhesion control strategy tended to remove the electric braking effort once a certain level of slide was detected and revert to an all friction brake mode of operation and control. However, advances in braking and traction system integration in recent years mean many of the latest generation EMUs now have electric braking control systems comparable in terms of ability to control slide to friction brake systems. These newer generation EMUs adopt complex control strategies to maximise the electric braking and keep it active in almost all but the most extreme slide scenarios.
- Electric brakes cannot generate much electrical energy when the train speed is low. For this reason, pneumatic disc brakes must be used to support electric brakes by blending in the friction brake as the effectiveness of the electric brake decreases. Again, recent advances in electric brake integration have reduced the blending speeds down to relatively low speeds of around 3mph, but friction braking is still required at these very low speeds. Blending of the two systems at low speed or indeed at high speeds and payloads, where the electric brake may not be able to support all the braking effort required, is done automatically without driver action.

Predictable and Optimised Braking
A blended braking approach

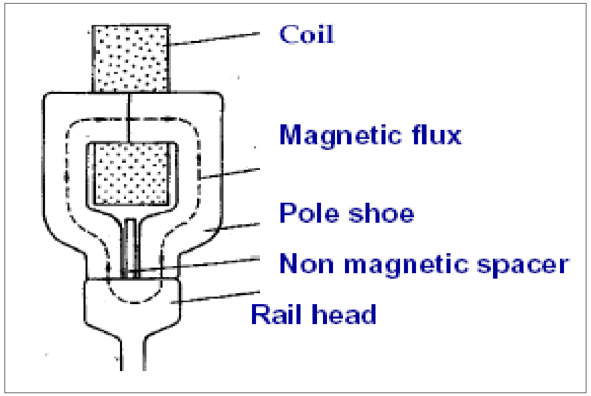
A consortium consisting of Alstom, the University of Huddersfield and TRL developed an 'Intelligent Blended Braking' (iBB) concept that blends adhesion systems to deliver predictable and optimised braking independent of the adhesion level. Capable of blending systems which are independent of wheel / rail contact (Eddy Current Brakes and Magnetic Track Brakes) and systems which work to raise adhesion levels (WSP and sanders), the benefits could include independence from the autumn timetable, a reduction in braking-related maintenance costs, and reduction in adhesion related delays and penalties.

RSSB R&D project SC04-POB-13

- The friction brake is still required as an emergency brake if the electric braking system were to fail.
- Due to the efficiency of modern dynamic brake systems, there is an increasing risk of the brake pads seeing little use in normal service and becoming polished or glazed. This effect can significantly reduce the friction level of the pads when they are called upon for a friction only application, particularly in wet conditions. In view of this, the control system should incorporate features to prevent this occurrence, such as regular friction only braking stops on one or more bogies with the targeted bogies being systematically varied between stops or runs.

5.1.3 Magnetic track brakes

There are three types of Magnetic Track Brake (MTB). Each type works by changing the kinetic energy of the train in to heat in the rail, which is a potential problem for these types of brake. Use as an emergency brake is not a problem; the occasional brake application into a rail will not cause a significant increase in rail temperature. However, repetitive brake applications from service braking patterns can cause rail temperature to increase to levels where the risk of track buckling must be considered and mitigated.



- Eddy Current Brakes do not contact the rail because train-borne equipment generates a magnetic field between the brake and the rail, bridging a 20mm gap. This brake type is fitted to a few high-speed European trains and works as an emergency brake and, in specific locations where the potential for track buckling can be contained, as a service brake.
- Electro-Magnetic Brakes (shown adjacent) use a brake frame containing electro-magnets and consumable magnet pole faces which contact the rail. The brake frame is lowered to contact

the rail and a simple DC current is passed through the electro-magnets on the frame, clamping the frame to the rail and generating friction between frame and rail. These brakes are widely used as an emergency brake in tram, metro, commuter and high-speed trains in Europe. They have also been used for many years on the Nexus (Tyne and Wear Metro) trains which operate, in part, on Network Rail infrastructure where they are used as an emergency brake. Informed by RSSB R&D project T1099 “Enabling Magnetic Track Brakes on GB mainline railway”, RSSB Rail Industry Standard RIS-2710-RST “Magnetic Track Brake” governs the use of these brakes on GB railways and facilitates assessment of infrastructure compatibility and identification of any mitigations required.

- Permanent magnet track brakes require no external electrical supply. This type of brake tends to be used on trams; they provide a very rapid increase in brake force which is not always acceptable in higher speed trains.

Electro-magnetic MTBs bring broadly similar adhesion benefits to sanders when adhesion is too low to support normal braking forces. Like sanders, MTBs can break up the contaminant layer on the railhead, thereby improving adhesion for the following wheelsets. They do this because of the very high temperatures generated at the brake interface with the railhead, hot enough to cause partial melting of the cast iron brake material. Importantly, the movement of the train along the rail prevents overheating of the rail during a single emergency brake application.

Excepting Eddy Current Brakes which do not contact the railhead, MTB braking performance can nonetheless still be affected by low adhesion. 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.

All MTBs have one major disadvantage; they require significant amounts of space below the bogie frame, between the wheels. Retro-fitting these brakes might be quite impracticable, if not impossible. On new build trains, where European manufacturers consider use of MTBs to be quite normal, it may be quite straightforward.

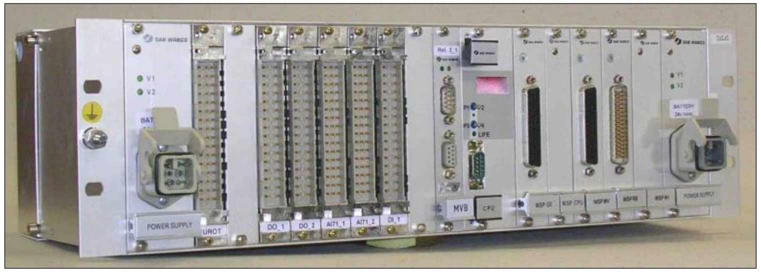
5.2 Optimising braking performance

From a train perspective, optimising braking performance in low adhesion means deploying devices to boost the available adhesion, and optimising brake control to make the best use of the available adhesion. This section describes:

- Wheel Slide Protection systems;
- Trainborne sanders;
- Aerodynamics to reduce contamination.

5.2.1 Wheel Slide Protection systems

WSP with disc brakes



The objective of Wheel Slide Protection Systems (WSPs) is to minimise the inevitable extension in stopping distance when low adhesion is encountered, whilst reducing the risk of significant wheel damage.

When adhesion is low and the driver brakes a train, the wheels may slide as they are gripped ‘too hard’ by the train brakes. As with anti-lock brakes on all modern motor cars, the manufacturers of train brake systems have devised control systems which over-ride the driver’s brake demand on an individual axle by axle basis and they briefly switch the brakes off (before switching them back on). Switching the brakes off, albeit briefly, is not something that is done lightly. Manufacturers have developed systems that have passed the most stringent safety tests, and which have provided very good performance in many countries around the world over many years. Appendix A1.3.1 describes the relevant standards and safety controls.

WSP systems look for wheel slide which will occur when the brake force on a wheelset exceeds the force that wheel / rail adhesion can withstand. Normal train braking typically requires adhesion of 3%, 6% and 9% between wheel and rail in brake steps one, two and three respectively. These are all well below the adhesion that is normally available

Edition 7, May 2024

(section 2.1). So, in normal driving conditions drivers can be confident that there will be enough wheel / rail adhesion to support normal train braking. Indeed the original intention when British Rail developed the nominal 9%g braking performance curves for modern disc braked trains was that the 9%g braking performance (0.88 m/s^2) could be supported by wet rails whose adhesion would typically be between 10% and 15%.

However, as all train drivers know, driving conditions are not always normal. Leaf fall in Autumn is famous for producing very low adhesion values which may be less than 2%, below the level that even brake step one would require. In such situations wheels will slide and will generate flats unless effective WSP systems are fitted and, more importantly, the driver will not get the braking effort requested.

Brake system manufacturers have devised processes that measure the speed at which individual wheelsets rotate, and the rate at which their speed changes, to determine when a wheelset is rotating more slowly than the train is moving. When this occurs:

- A signal should be passed to the cab to inform the driver that wheel slide is happening;
- Sanders are activated (section 5.2.2);
- Brake force on the sliding wheelset is reduced until the wheelset speed begins to 'catch up' with train speed, when the requested brake force is re-applied.

If wheel slide recurs, the above process repeats until the train stops. Many WSP systems aim to allow some wheel slide as this is believed to maximise the available adhesion. Typically, once low adhesion is encountered, WSP systems aim to have the wheel rotating approximately 15% more slowly than train speed.

By having individual wheelset control, the overall effect is far superior to that which could be achieved by a driver trying to control the slide by applying and releasing the brake, as the driver's actions would alter the braking on all wheelsets, whereas the WSP system controls at wheelset level.

Modern WSP systems can also:

- Include a function that determines the level of adhesion the wheelsets are seeing and adapts the control algorithm to change the targeted level of slide to be more suitable for the conditions. This allows the wheels to achieve a higher level of adhesion, thus leading to shorter stopping distances.

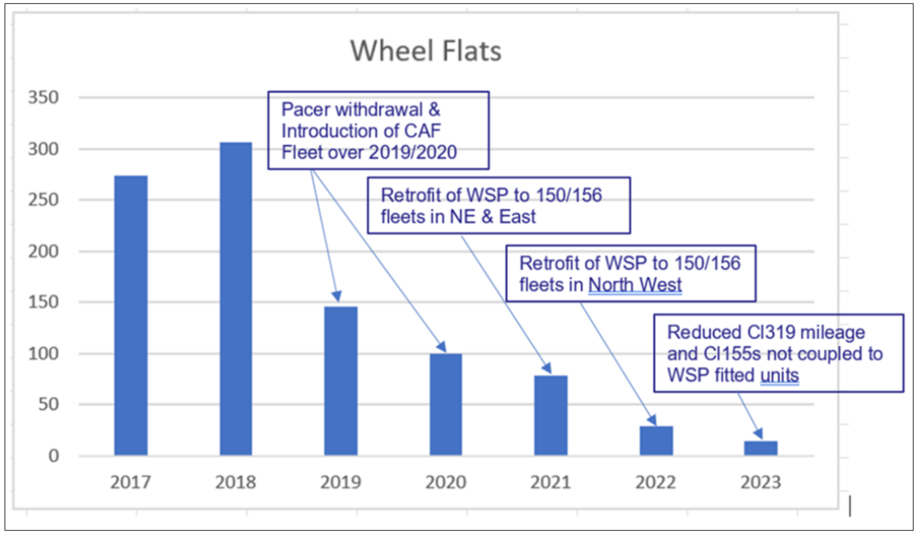
Edition 7, May 2024

- Control the dynamic brake directly which allows the two systems to work in parallel. Previously, it was common for the dynamic brake to be inhibited during wheel slide, leading to greater pad and disc wear. The use of the friction brake control system to control the dynamic brake therefore maximises the use of the dynamic brake and makes the train more energy efficient.

WSP with tread brakes

Historically WSP systems have been fitted to disc braked units, however Northern has significantly reduced wheel flats in recent years by progressively fitting it to their older tread braked Sprinter fleets:

- None of their 66 Class 156 units were recorded as suffering wheel flats after WSP was fitted;
- Ensuring non-WSP units don't operate with WSP units also helps to reduce flats;
- Their lathe now has spare capacity!



WSP on freight wagons

Lack of electrical power, not to mention cost pressures, have meant that freight wagons are not usually fitted with WSP systems. However, in collaboration with VTG on their iWagon (section A1.5.11), Knorr-Bremse have developed a Wheel Flat Prevention system called Sentinel. This uses axle end generators to produce the electrical energy required by Sentinel and the wagon monitoring system.

Incidents like the derailment at Petteril Bridge Junction (19 October 2022), where the initial wheel slide was probably the result of a brake application made in low adhesion conditions, underline the value of such systems in wagons.

5.2.2 Trainborne sanders

There are three main types of sanders:

- Emergency Sanding Device (ESD) – these sanders were fitted to a few fleets such as Class 158 and 159s in the 1990s. They consist of a sealed CO_2 canister and a single charge of sand which, in emergency braking, discharges sand at a higher rate than permitted by current standards. These sanders are highly effective at stopping a train but they only function once, so installations doubled the canisters to avoid trains being withdrawn from service after one operation, requiring drivers to manually select the reserve sand supply after the initial supply had been deployed.
  High sand delivery rates increased the risk of track circuit actuation problems, and ESD have not been permitted on new build rolling stock since 2001 due to the publication of GMRT2461 (see below). 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 were fitted with ESD. It is likely that none of these sanders are still in service.
- Fixed Rate Sander – this type of sander is by far the most common sander on GB railways. The sander consists of a sand hopper, a compressed air supply and a valve that uses the energy of the compressed air to blow sand through a rubber hose towards the wheel / rail nip. This sander discharges sand at a nominal rate of 2kg/minute, although some sanders have been increased to 3kg/minute. The principal disadvantage with fixed rate sanders is that the sand discharge rate is a compromise governed by limiting the discharge rate at low speed. This is to avoid a train coming to a rest on sand and not reliably operating track circuits. As such, the fixed sand discharge rate is sub-optimal at high speeds.

- Variable Rate Sander – this type of sander has been tested under RSSB R&D project T1107 demonstrating considerable advantages over fixed rate sanders:
  - In its simplest form, the sand discharge rate varies in steps according to train speed: typically 4kg/minute at higher speeds and 2kg/minute as lower speeds. The components of this sander are the same as for the fixed rate sander, but with more complex control of the sand valve. Elizabeth Line Class 345s are fitted with double sanders of this type delivering 3kg/minute or 1.5kg/minute dependent on a number of parameters including speed and the level of adhesion.
  - True variable rate sanders, where the discharge rate changes in proportion to speed, have recently become available and are fitted to SWR Class 158 and 159s. These sanders have a higher mean sand discharge rate and can continue to discharge sand at speeds to standstill, whilst still being fully compliant with standards. The higher mean sand discharge rate provides greater adhesion benefits than the simpler variable rate sander that switches between different levels.

Sand particle entrainment and its effects on the interface

This University of Sheffield PhD (COF-ITR-02) assessed a range of particles and found:

- Multiple wheel passes had little effect on adhesion in dry and wet conditions, whereas it decreased on leaf contamination;
- In dry and wet conditions, increasing normal pressure saw an increase in adhesion, whereas it decreased on leaf contamination;
- In dry conditions, much of the sand was expelled out of the contact patch upon being crushed, whereas in wet conditions a greater amount was retained.

The work informed COF-UOS-03 which tested and analysed newly developed sand alternatives designed to enhance track circuit performance. A follow-on project (COF-UOS22-03) is planning to conduct a live operational trial of the enhanced sand with Northern.

RSSB R&D project COF-ITR-02; COF-UOS-03; COF-UOS22-03

Edition 7, May 2024

GB trains can have multiple sanders active on a unit. **Units operating in multiple can, and should have all of their sanders active**.

Railway Group Standard GMRT2461 "Sanding Equipment" defines the current requirements for sander design, performance, and fitment to trains. A major goal of this standard is to provide a compromise between the good and the bad of sand in the wheel / rail interface. Increasing sand discharged into the wheel / rail interface is:

- Good because more sand increases adhesion (at least up to 5kg/minute);
- Bad because more sand increases the risk of track circuit failure as the sand insulates the wheel from the rail.

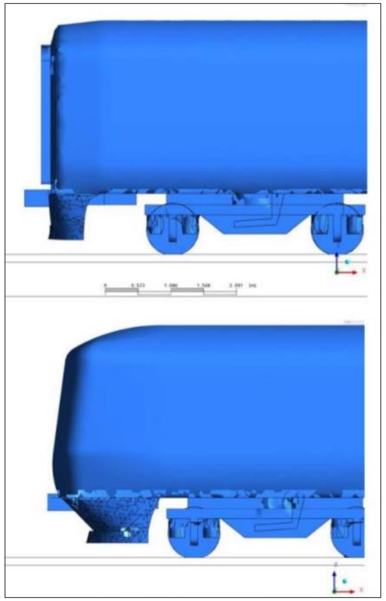
As well as demonstrating the advantages of variable rate sanders over fixed rate sanders, RSSB R&D project T1107 also demonstrated significant improvement in adhesion levels and braking performance by increasing the number of sanding positions on a train. Double Variable Rate sanders, i.e. two Variable Rate Sanders on a train, are described in appendix A1.5.7.

RSSB R&D project T1210 developed good practice guides on:

- Sander maintenance and replenishment for depot teams to ensure that sander systems deliver sand as designed;
- Integration of sanding systems onto railway vehicles.

More detail on sanders generally is available in appendix A1.3.2.

5.2.3 Aerodynamics to reduce contamination



Simple observation of a train passing through autumn woodland shows airflows from the train lift leaves into the air and allow some of them to settle on the rails.

BR Research conducted tests in the 1990s revealing that the number of leaves left squashed on the railhead after a two-car Sprinter DMU was highly dependent on both the presence and type of air dam fitted to the front of the train. A very limited understanding of the leaf movement 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 trainborne 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.

Wind tunnel work at the University of Southampton with Computational Fluid Dynamics (CFD) in the early 2000s (RSSB R&D project T546) identified factors that 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;
- The bluff front end of the Class 158 creates a much more erratic flow around the vehicle sides compared to the smooth airflow off the rounded front end of the Class 165.

There are other factors that determine the design of the front end, and it is believed that the above thinking has not progressed further.

5.3 Improving train detection

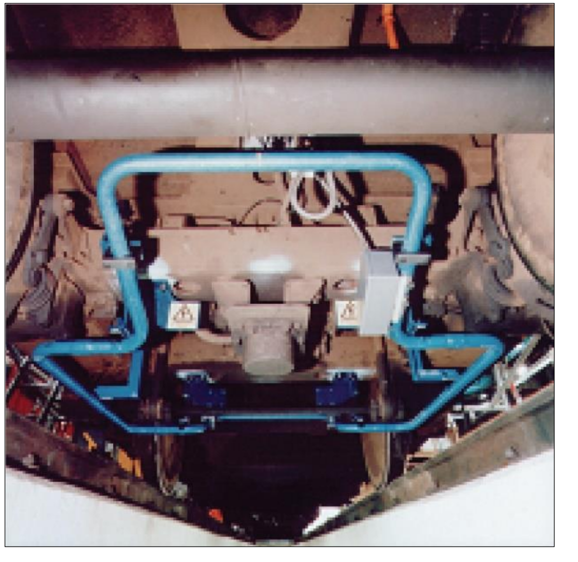
Low adhesion not only has potential to compromise a train's ability to stop, the contamination on the railhead and wheels as a result can compromise track circuits and prevent trains being detected. This section discusses two aspects of train design that have been used to mitigate this risk:

- Track Circuit Assisters;
- Auxiliary Tread Brakes.

5.3.1 Track Circuit Assisters

The aim of the Track Circuit Assister (TCA) (aka Track Circuit Actuator) is to assist the operation of track circuits by breaking down the electrical insulation properties of certain contaminants on the railhead.

TCAs were deployed to mitigate WSTCFs following the introduction of lightweight, smooth running and disc braked (as opposed to tread braked) Diesel Multiple Units (DMUs) in the 1980s. On lightly used lines, the rust that formed on the railhead was 'rolled' by the new DMUs, instead of clearing it, forming an electrically insulating film. The properties of the rust film were such that lower voltage track circuits were no longer shorted out by DMU axles, and consequently the signalling system failed to detect trains reliably.



If a high enough voltage is created across the insulating layer, it breaks down rust film, allowing track circuit current to flow, de-energising the track circuit relay, and detecting the train. TCAs can be fitted to provide this high voltage by raising the effective track circuit rail-to-rail voltage at the wheelsets either side of the TCA. This enables a low voltage track circuit to operate as effectively as a higher voltage type.

The equipment is relatively simple: a metal loop mounted beneath the train (for example the blue loop in the photo above) 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.

However, TCAs have some limitations:

- They were designed to deal with railhead contaminants such as rust, without interfering with the normal operation of track circuits or affecting staff safety. 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. The TCA Interference Detector (TCAID) was developed to address this (section 6.2.3).
- **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** (see below).

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 developed a ‘Risk Advisor Tool’ that enables train operators to assess the risk of operating specific classes of train over generic classes of route with TCAs not fitted or not operational (RSSB R&D project T579 and T1005). Application of the tool is explained in Rail Industry Standard RIS-2777-RST “Functionality and Management of Track Circuit Assisters (TCAs) on Rail Vehicles” which offers guidance on:

- Informing Defective On-Train Equipment (DOTE) management plans;
- Deciding on whether to fit the TCA to a new train;
- Deciding on whether to remove the TCA from existing trains.

RSSB R&D project IMP-T579 is currently updating and expanding the Risk Advisor Tool for passenger trains; and is producing an up-to-date map of TCAID locations on the GB mainline.

Edition 7, May 2024

Railway Group Standard GMRT2477 "Compatibility Requirements for Track Circuit Assisters (TCAs) on Rail Vehicles" sets out mandatory requirements for the provision and operation of TCAs.

5.3.2 Auxiliary Tread Brakes

Auxiliary Tread Brakes (ATB), aka 'Scrubber Blocks' were explicitly fitted to clean the wheel treads to improve train detection and wheel / rail adhesion, and not braking per se. ATBs are applied each time the driver applies the brakes and rub against the wheel tread thus cleaning it; the disc brakes remain responsible for the service braking.

ATBs were fitted to relatively light weight disc braked DMUs in the 1990s, including Class 158 and 159s, and are still in place today. On initial service introduction, Class 158s experienced greater rates of failure to operate track circuits than the previous tread braked Class 15X fleets. Trials were conducted by the then Regional Railways and British Rail Research on test trains at the Old Dalby test site. It was established that a relatively small cast iron brake block scrubbing the wheels helped clean them sufficiently that, in combination with the Track Circuit Assisters (TCA) (section 5.3.1), the Class 158s operated track circuits acceptably.

However, ATBs have some limitations:

- ATBs only operate when a brake application is made, but the wheels will still be in better condition than if ATBs were not fitted;
- Recognising ATBs were designed for DMUs, ATBs would not be applied if a brake application was entirely electric;
- ATBs increase the noise and vibration inside the vehicle thus worsening the passenger environment.

No recent trains in use on GB railways have these devices fitted.

5.4 Managing wheel flats

Correctly working WSP and sander systems mitigate the impact of low adhesion on braking and, in so doing, minimise the risk of wheel flats during the Autumn. However, wheel flats can still occur and significant flats will stop trains going into service until they can be removed. Depot wheel lathes are the prime means by which this is achieved, so steps need to be taken to check they are working correctly and reliability in the run up to the Autumn when their contribution to fleet availability is particularly important. Wheel lathes have been known to fail and the autumn period is not immune to this.

This is not about reactive management when a wheel lathe goes down, but proactive management planning many months ahead. For example:

- An agreement should be in place with the lathe maintainer to rectify faults within a suitable timeframe, whilst ensuring they have prompt access to critical / long-lead time spares for the lathe;
- An agreement with operators of neighbouring wheel lathes is in place, and the route compatibility work has been done to enable vehicle transit to them if the usual lathe is not available;
- Major maintenance / renewals of the lathe are carried out prior to the 'leaf fall' to avoid major planned outages during the critical period;
- There is prompt access to sufficient spare wheelsets and / or bogies;
- Getting ahead of plan with routine work that occupies the depot equipment needed to change wheelsets / bogies;
- Annual leave of the wheel lathe staff is managed to avoid accumulated leave being taken during the critical 'leaf fall' period prior to year-end;
- Eliminate the number of units stopped for turning in advance of the 'leaf fall', and check there is sufficient wheel life left prior to the start of the season;
- Get ahead of plan with the planned turning schedule so vehicles with flats can be slotted in when required.

5.5 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 discusses:

- On-Train Data Recorders;
- Forward Facing CCTV;
- Remote Condition Monitoring systems.

5.5.1 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 A1.4.1.

5.5.2 Forward Facing CCTV

Most mainline passenger trains are now fitted with a Forward Facing CCTV (FFCCTV) camera looking ahead of the train. Such devices can provide information on track condition and 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:

- Greater Anglia, for instance, has used portable cameras fitted to one of their vehicles, to enable quick identification of vegetation issues as part of autumn preparation;
- CrossTech, a UK-based technology company, have developed a system called Hubble which uses Artificial Intelligence to detect overgrown vegetation next to the railway using footage from FFCCTV or handheld cameras on trains, and automatically flag when signage is obscured. Network Rail have been trialling Hubble since 2021 in the Southern region and it has helped them reduce the incidents of foliage obscuring signals, although that is no substitute for proper sighting checks by an expert.

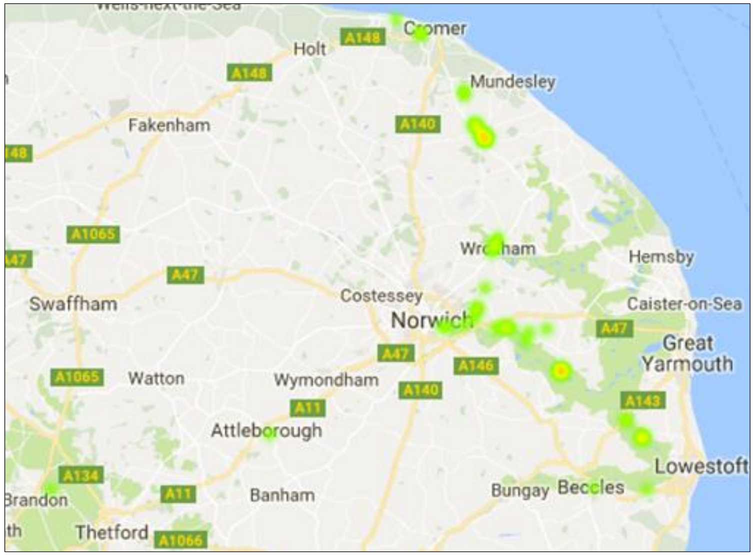
Footage may also be used to benchmark the foliage on the route for use as a comparison in future reviews. FFCCTV has also been used during buffer stop collision investigations to verify the speed of impact.

Low adhesion estimation through image machine learning

Work by RSSB and the University of Sheffield is taking this a step further by investigating if images from cameras looking at the railhead, supported by images from FFCCTV and other sensor data, can be used to deliver more accurate and granular predictions of railhead adhesion. The work builds on RSSB R&D project COF-UOS-02 "Neural Network-Based Regression for Local Adhesion Estimation" which demonstrated this approach. The capability is still in its infancy and current work is using high-resolution FFCCTV footage to build the algorithm and enhance the tool's predictive capabilities. RSSB R&D project COF-UOS22-02

Edition 7, May 2024

5.5.3 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 later addition. This technology enables a wealth of data on train condition to be made available to the wayside in real-time. In the past, the challenge has often been turning that mass of data into actionable information, however advancements in computing analysis like Artificial Intelligence now make that easier.

Although only available when the train is braking, the level of WSP activity and its duration indicate the presence of low adhesion. This data and its location can be transmitted to the wayside in real-time. Therefore:

- Arrangements need to be put in place to make effective use of this information for: briefing drivers; implementing short-term countermeasures; and, seasonal planning;
- Where trains are planned to be fitted with RCM systems, consideration should be given to ensuring these systems provide WSP activity, location recording and reporting.

Some examples of the systems available are listed below, but this is by no means a complete list:

- Notus – this system from Mistral Data displays the location of WSP activity on a Google Map view. The system receives WSP, braking and traction data from live OTDR data. The threshold is based on WSP activity that lasts over 7 seconds within the past 24 hours. It is currently used by South Western Railway and provided to drivers' tablets and control centres.

Edition 7, May 2024

- Seasonal Intelligence Platform – this system from Route Reports, partnering with Porterbrook and Network Rail, enables 'real time' low adhesion mapping, treatment train monitoring (for missed sites) and provides information on which low adhesion sites affect performance and to what extent. Data sources include live GPS data, live WSP data from OTDR (from Govia Thameslink Railway) and Met Office data.
- Trimble Nexala Solutions has a suite of 'intelligent rail asset management solutions'. The software transmits remote diagnostic information (such as WSP events) to control centres. It is used by several operators including South Western Railway, Greater Anglia and Eurostar.

5.6 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 AWG investigation ('the Goff report') and RAIB investigations. To minimise the risk that low adhesion adversely affects new train fleets in their early life, some key messages have emerged:

- Read the RAIB reports into the 2005 adhesion incidents, 'the Goff report' and this manual; check that prospective suppliers have also read them;
- Question 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;
- Check that 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, the interpretation of standards particularly on 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. Variable Rate Sanders, and, in particular, Double Variable Rate Sanders (DVRS) should be given serious consideration even though the benefits of a DVRS fleet fit have yet to be proven and go live for Autumn 2024 (section A1.5.7);

Edition 7, May 2024

- Integrate monitoring of WSP and sanding activity with the overall onboard data management and Remote Condition Monitoring (RCM) capability of the train;
- Design the systems in a way that makes it easy to share FFCCTV, WSP and other data with Network Rail to allow effective joint decision making about vegetation work, treatment circuits, etc;

Published by RSSB, RDG's Key Train Requirements should also be consulted. It is not specific to adhesion, but it is essential reading for those buying new trains.

6 Train detection measures

Some forms of rail contamination, not to mention its treatment, can lead to trains failing to activate track circuits. 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 equipment to operate level crossing barriers (Norwich Road level crossing).

The introduction of new lightweight Diesel Multiple Units (DMUs) in the late 1980s / early 1990s caused more WSTCFs than the units they replaced. The ensuing research by BR identified:

- That low voltage DC track circuits were particularly vulnerable where modern Diesel Multiple Units (DMUs) with good riding bogies and disc brakes operated;
- A range of solutions for the most common cause of WSTCF – rust film on the rail – although not always effective for other causes such as dry leaf film and excessive use of adhesion modifier. As a result, the railway continues to suffer a number of WSTCFs every year (section 2.4).

Note also:

- WSTCF locations do not necessarily coincide with low adhesion locations identified for traction / braking problems, as track circuit failures can occur at locations where trains do not normally need to accelerate or brake;
- It is rare to have both adhesion and track circuit problems at the same time; poor adhesion requires damp conditions while poor track circuit performance requires dry conditions.

Edition 7, May 2024

This section describes the main issues involving loss of train detection during the autumn period and methods of controlling this:

- Operational procedures;
- Improving track circuit performance;
- European Rail Traffic Management System (ERTMS).

Further detail on WSTCF issues is available in AEA Technology report AEAT-T&S-2000-101 "Review of Initiatives – Wrong Side Track Circuit Failures", August 2000. Appendix A7 provides further details on reviews of WSTCF performance.

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 as per the Rule Book (GERT8000-TW1). This section describes:

- Signalling controls;
- Level crossing controls;
- Other warning systems;
- Double blocking;
- Examination of the train;
- Service / fleet withdrawal or diversions;
- Hybrid / mixed train operations.

Further guidance is available from Rail Industry Standard RIS-3708-TOM "Arrangements Concerning the Non-Operation of Track Circuits During the Leaf Fall Contamination Period" which supports train / freight operators in satisfying their legal obligations in respect of providing contingency arrangements. It contains elements for identifying the need for, introduction and subsequent removal of, restrictions to normal operations in the event of problems being encountered with the operation of track circuits during the leaf fall contamination period.

6.1.1 Signalling controls

As per the Rule Book, signalling equipment must be operated to avoid the need for signals to be passed at danger. The affected section must be capable of being protected by a signal under the direct control of the signaller. The signaller must 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 must not be operated until the train is well clear. The individual point control devices must be used on a route setting system. Reminder appliances must 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 (RHTT) when laying and the train following it;
- A train with a failed Track Circuit Assister (TCA) (section 5.3.1);
- When track has not been used for some time, as electrically insulating rust is likely to have formed on the railhead (RSSB R&D project T1222).

6.1.2 Level crossing controls

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

6.1.3 Other warning systems

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

6.1.4 Double blocking

To prevent having two trains in the same section at the same time, rules must be instigated that require two signalling sections to be proved clear between successive trains, so that if there is a WSTCF the signal in rear does not give a proceed aspect. 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 a train or vehicle fails to operate a track circuit, the signaller must arrange for the train to be stopped at the first available location so that the wheelsets can be examined, if necessary, by the driver to identify whether the train must be taken out of service. Drivers, of course, need to be trained in what to look for on the wheels.

Responding to contamination on wheelsets

Train operators should have an agreed process to follow if contamination is found on the wheelset during the inspection. The process should take into account the type and extent of the contamination found, the number of track circuits that have failed, the practicality of removing the train from the network, whether the contamination will wear off before the train can be removed from the network, and if the risk of further failures is mitigated by any features of the rolling stock or the infrastructure the train will run over (e.g. scrubber blocks fitted to train, rest of journey is detected by axle counters, etc.). If it is determined necessary, based on the aforementioned process, any contamination should be removed from the wheelsets before the train enters back into service.

P18 of guidance from RSSB R&D project T1222

6.1.6 Service / fleet withdrawal or diversions

Diversions must 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 must be considered. DMUs must not be permitted to run over the sections of line where Automatic Half Barrier level crossings are operated solely by track circuits.

Reallocating problem fleets

*As a **last resort**, if a particular fleet is persistently creating WSTCFs on a line even after all appropriate mitigations have been undertaken, consideration should be made as to whether it is best to remove the fleet entirely from the line.*

P35 of guidance from RSSB R&D project T1222

6.1.7 Hybrid / mixed train operations

Disc braked DMUs with modern bogies are more vulnerable to WSTCF due to leaf debris building up on the wheel treads. The mixing of disc braked and tread braked units, or the addition of tread braked vehicles into disc braked units (hybrid formation), can assist in but not guarantee correct operation of track circuits in vulnerable areas. Note though that, combining WSP fitted units with non-WSP fitted units in the same train is likely to increase wheel flats on the non-WSP unit (section 5.2.1).

Recognising fleet diversity

As less diverse traffic can lead to tighter running bands, more of the railhead may contain contamination upon which WSTCFs can occur. This raises the risk of other (infrequent) traffic that runs out of the dominant running band. On the other hand, a more diverse mix of traffic will result in more of the railhead being used, resulting in less contamination. Therefore, increased WSTCF risk for lines with dominant train classes/types should be recognised, and further mitigations should be implemented.

P33 of guidance from RSSB R&D project T1222

Also, if routing options allow, running freight trains on routes normally only used by passenger multiple units will assist clearing contamination from the rails. Provided they won't stall on gradients with low adhesion, this may be particularly effective when there is a history of track circuit problems in the Autumn. For example on the Test Valley line where low voltage DC track circuits were historically affected by contamination, operated predominantly by Class 158 DMU which do not 'scuff' the rail significantly; track circuit operating problems reduced significantly after diverting three freight trains a day over the route.

6.2 Improving track circuit performance

Once the risk of WSTCFs has been mitigated as far as possible through operational procedures, there are various ways of improving the performance of the track circuits themselves in low adhesion.

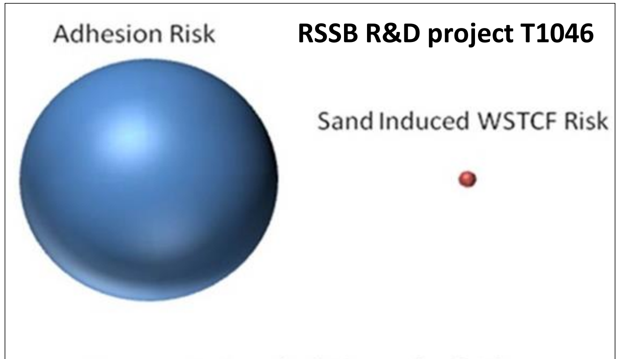
This section describes the following (trainborne Track Circuit Assisters are covered in section 5.3.1):

- Track circuits;
- Track circuit monitoring;
- Track Circuit Assister Interference Detectors;
- Design for Reliable Track Circuit Operation;
- Axle counters.

These cannot be considered in isolation; the system for managing low adhesion risk needs to be considered as a whole: vegetation needs to be managed (section 4.2); treatments need to be applied (section 4.3); and trainborne mitigations (section 5) such as sanders need to be operating effectively. However, 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 (RSSB R&D project T1046) concluded this is not the case: 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 (see adjacent).

RSSB R&D project T1046



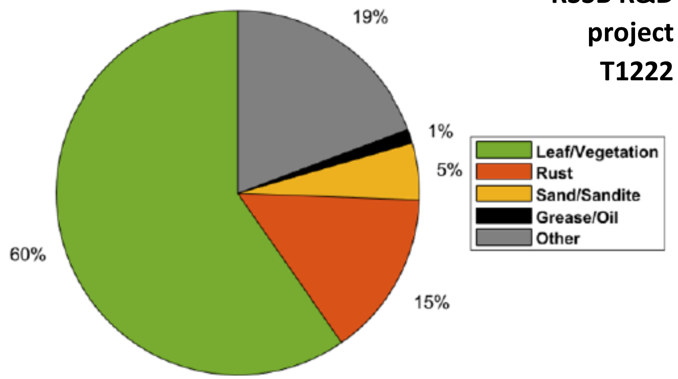
Representation of relative scale of risk

In 2023, further work (RSSB R&D project T1222) analysed WSTCFs on six ‘case study’ lines, concluding:

- Over a 10 year timeframe (2012-2022), approximately 93% of track circuits on the GB mainline experienced no WSTCFs. The majority of track circuits which did experience a contaminated WSTCF only experienced one WSTCF. A minority of track circuits experiencing multiple WSTCFs.

- 60% of WSTCFs were attributed to leaf contamination, whilst rust contamination was attributed to a significant minority of incidents (15%).
- On Wales and Western routes, rust contamination accounted for the highest proportion of WSTCFs (35% and 36% respectively).
- Passenger trains accounted for approximately 75% of WSTCFs (of which 12% were attributed to empty coaching stock), whilst freight trains accounted for 25% of WSTCFs (of which approximately 9% were attributed to 'light locomotives').
- A higher frequency of WSTCFs occurred on short track circuits, with over 11% of all WSTCFs occurring on track circuits shorter than 20 yards.
- DC track circuits contributed to the highest proportion (44%) of contamination attributed WSTCFs, when normalised by the amount of each type of track circuit on the network.
- Overall, DC track circuits with leaf contamination in Autumn resulted in the most WSTCFs.

RSSB R&D project T1222



Breakdown of attributed causes of WSTCFs in Great Britain ('Other' represents WSTCFs without contamination being the assigned cause)

The project produced two good practice guides:

- Mitigations to reduce WSTCF;
- Guidance for operators and infrastructure managers following a WSTCF.

Combined, the two documents incorporate over 50 'points of action', including:

- Removing vulnerable DC track circuits (where practicable);
- Undertaking regular Remote Condition Monitoring (where available) to predict future WSTCFs;
- Where a track is rarely used, it is more likely that rust will form on the railhead, which can lead to WSTCFs:
  - These rarely used lines should be identified during an evaluation of the risk of WSTCFs;

- Further monitoring and mitigations should be undertaken.

The outputs will inform changes to Rail Industry Standard RIS-3708-TOM “Arrangements Concerning the Non-Operation of Track Circuits During the Leaf Fall Contamination Period”.

6.2.1 Track circuits

Sequential track circuits

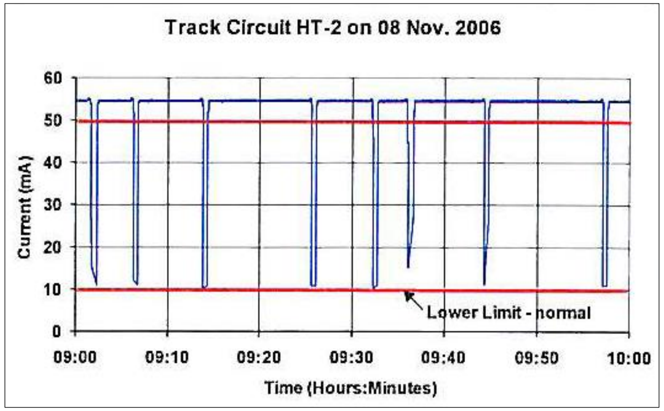
When sequential track circuits are used, they must occupy and then clear in the correct order to prove that the whole of the train has passed through that section of line. They are not used very much now, because it is very difficult for the maintainer to identify right side failures.

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. As mentioned above, research by RSSB in 2015 and 2023 (RSSB R&D project T1046 and T1222) concluded that 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.

Edition 7, May 2024

6.2.2 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 adjacent image 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 staff to react to emerging conditions and prevent a WSTCF occurring.

Network Rail is now monitoring around 30,000 track circuits.

Investigating the effect of inductance in relay coil

It was observed that the role of inductance in the coil of the relay contributed to large increases in voltage and was a significant determinant of overall track circuit behaviour….It was noted that many nominally DC track circuits are, in reality, using unidirectional AC (not smoothed DC or from batteries), so inductance within the circuit is much more significant than might be expected for a genuinely DC system. Alternative designs to this, including replacing the coil with a solid-state relay, would mitigate against this effect.

P18 of guidance from RSSB R&D project T1222

Edition 7, May 2024

6.2.3 Track Circuit Assister Interference Detectors

As explained in section 5.3.1, Track Circuit Assisters (TCAs) have been fitted to modern DMUs to aid the operation of track circuits. Track Circuit 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 A1.2.11.

6.2.4 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 GKRT0028 “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.

6.2.5 Axle Counters

Axle counters are progressively being installed as a replacement to track circuits. They detect the present of the train by the wheel rims either moving a treadle, or being electronically detected by wayside sensors. They do not rely on the wheelsets electrically shunting the rails and, hence, eliminate the effect of rail contamination on train detection.

6.3 ERTMS

Transmission based signalling is gradually being introduced as a replacement for conventional lineside signalling. Systems such as the European Train Control System (ETCS) will predominantly use axle counters for train detection, eliminating risk to train detection from rail contamination.

Edition 7, May 2024

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 GB 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 called the Driver Machine Interface (DMI). 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.

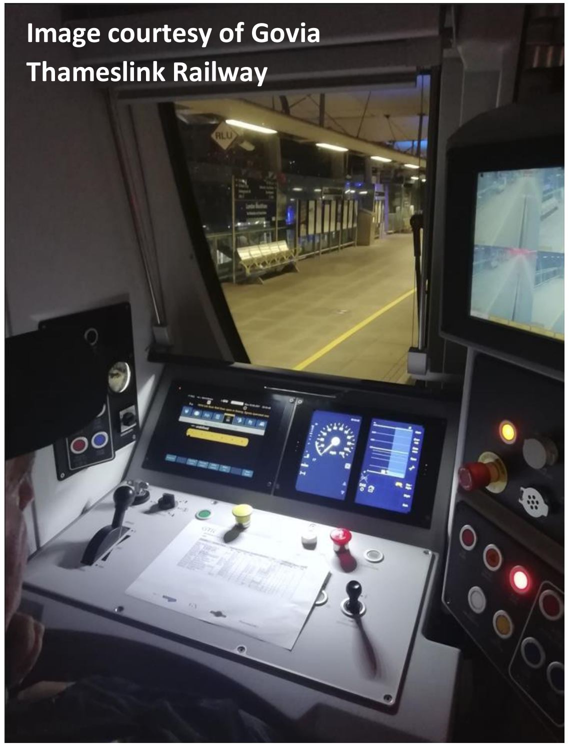


Image courtesy of Govia Thameslink Railway

It is also fundamental that ETCS remains fully operational throughout periods when a train is experiencing wheel spin or wheel slide, which of course is highly likely under low adhesion conditions. Wheel spin 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 could 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. Some recent trains can have an unbraked and unpowered wheelset to prevent wheel spin / slide, however such trains need to be fixed formations of several vehicles to avoid significant impact on braking performance.

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. 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. However, it is expected that drivers will be able to set the DMI to display a 'Low Adhesion' icon as a reminder that adhesion levels are sub-optimal.

7 Abbreviations

AC	Alternating Current
ACC	Adhesion Control Centre
ACCAT	Adhesion Controller's Condition Assessment Tool
AHBC	Automatic Half Barrier (level) Crossing
AIVR	Automated Intelligent Video Review
ALARP	As Low as Reasonably Practicable
AMS	Adhesion Management System
ARG	Adhesion Research Group
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
CCF	Control Centre of the Future
CCS	Control, Command and Signalling
CEN	Comité Européen de Normalisation
CFD	Computational Fluid Dynamics
CIRO	Chartered Institution of Railway Operators
COSHH	Control of Substances Hazardous to Health (Regulations)
CPL	Carriage Packing and Labelling (Regulations)
DC	Direct Current
DMI	Driver Machine Interface
DMU	Diesel Multiple Unit
DOTE	Defective On-Train Equipment
DVRS	Double Variable Rate Sanders
EMU	Electric Multiple Unit
EoA	End of Authority
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
FFCCTV	Forward Facing CCTV
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
HMG	His Majesty's Government
HST	High Speed Train
IBJ	Insulated Block Joint
JSMG	Joint Seasonal Management Group
KPI	Key Performance Indicator
LILAC	Leaf-Induced Low Adhesion Creep

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Managing Low Adhesion

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MOM	Mobile Operations Manager
MPV	Multi-Purpose Vehicle
MTB	Magnetic Track Brake
NPB	Network Performance Board
NR	Network Rail
NSC	National Supply Chain
NTF	National Task Force
NTSN	National Technical Specification Notice
OEM	Original Equipment Manufacturer
OTDR	On Train Data Recorder
OTP	On-Track Plant
PDP	Professional Driving Policy
PPM	Public Performance Measure
PR	Public Relations
R&D	Research and Development
RAIB	Rail Accident Investigation Branch
RAMP	Railhead Adhesion Management Plan
RCF	Rolling Contact Fatigue
RCM	Remote Condition Monitoring
RGS	Railway Group Standard
RHTT	Rail Head Treatment Train
ROGS	Railway and Other Guided Transport Systems (Safety) Regulations 2006 (as amended)
ROLA	Reports Of Low Adhesion
RRV	Road Rail Vehicle
RSSB	Rail Safety and Standards Board
S&C	Switches and crossings
SCCG	Seasonal Challenge Communications Group
SCO	Network Rail Supply Chain Operations
SCSG	Seasonal Challenge Steering Group
SMD	Specially Monitored Driver
SMIS	Safety Management Intelligence System
SMS	Short Messaging Service
SPAD	Signal Passed at Danger
SPAR	Signals Passed at Red
SRM	Safety Risk Model
SRT	Sectional Running Time
SSSI	Site of Special Scientific Interest
TAT	Tactical Adhesion Teleconference
TCA	Tract Circuit Assister / Actuator
TCAID	Tract Circuit Assister Interference Detector
TGA	Traction Gel Applicator
TIGER	Track Is Good, Expected, Reportable
TOPS	Total Operations Processing System
TPWS	Train Protection and Warning System
TRL	Transport Research Laboratory
TRUST	Train Running System TOPS
TSI	Technical Specification for Interoperability
TSR	Temporary Speed Restriction
UIC	Union Internationale des Chemins de Fer
UKRRIN	UK Rail Research and Innovation Network
WILAC	Water-Induced Low Adhesion Creep
WON	Weekly Operating Notice
WRAPP	Weather Resilience App
WSTCF	Wrong Side Track Circuit Failure
WSP	Wheel Slide Protection system
WSPER	WSP Evaluation Rig
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.
Adhesion Modifier, aka Sandite / Traction Gel / TG60	A viscous water-based gel containing sand to improve rail adhesion, and a metal additive to aid track circuit activation.
Autumn Adhesion Index (AAI)	A predicted measure of risk likely to be encountered on an autumn day.
Automatic Train Operation	A system where the train is driven automatically by a control system.
Auxiliary Tread Brake (ATB) aka Scrubber Blocks	Cast iron or composition blocks pressed against the wheel tread to remove wheel borne contamination.
Line Proving	A method of proving that the railway is working correctly with the normal operation of the train detection and signalling system. Line proving can be carried out with any train that can be relied upon to occupy track circuits.
Sander, fixed rate	A sanding device that operates at a constant sand dispensing rate, so that the sand-laying density increases as vehicle speed decreases (GMRT2461).
Sander, variable rate	A sanding device for which the sand dispensing rate varies with vehicle speed, and which can be used to control sand-laying density (GMRT2461).
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. Note

	that this term is used differently in the Rule Book (GERT8000-TW1) where it means wheel spin as defined below.
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 Assister (TCA) aka Track Circuit Actuator	Trainborne device used to assist shunting of track circuits.
Track Circuit Assister Interference Detector (TCAID)	Track mounted device used to operate track circuits when the TCA frequency is detected in running rails.
Water jetting	High pressure water jets used to clean debris from the running rail surfaces.

Definitions of rail adhesion conditions from the Rule Book (GERT8000-TW1):

Good	Rail adhesion conditions are good.
Expected	Rail adhesion is no worse than would be expected for the location and environmental conditions.
Reportable	Rail adhesion is worse than would be expected for the location and environmental conditions.

Edition 7, May 2024

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Edition 7, May 2024

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Edition 7, May 2024

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Edition 7, May 2024

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Edition 7, May 2024

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Edition 7, May 2024

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More information is available

- Railway Group Standards are available direct from RSSB's standards catalogue web site https://www.rssb.co.uk/standards-catalogue
- Network Rail standards and are available from the Network Rail Standards Portal once registered via the link at https://www.networkrail.co.uk/industry-and-commercial/third-party-investors/network-rail-is-open-for-business/reviewing-our-standards/
- RSSB material may be obtained direct from https://www.rssb.co.uk
- Many reports, including some AWG documents and historical British Rail Research reports before 1996, are available on RSSB's SPARK free knowledge hub at https://www.rssb.co.uk/spark

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A1 Measures in detail

This appendix provides further information on some of the measures mentioned earlier. They are only included in this appendix where it was inappropriate to include such detail earlier. A complete list of measures can therefore be found in the previous sections.

Measures spanning the following areas are covered in this appendix:

- Operational measures;
- Infrastructure measures;
- Rolling stock measures;
- Information measures;
- New and emerging measures.

A1.1 Operational measures

This section provides further detail on some of the operational measures that are mentioned earlier:

- Driving cab simulators;
- Weather Resilience App (WRAPP).

Edition 7, May 2024

A1.1.1 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 to life’, driving cab simulators can be an effective form of training because:

- The simulation can be repeated over and over again, or varied at the instructor’s wish;
- Driving cab simulators can also be used to replicate operational requirements regarding low adhesion, for example carrying out a controlled test stop at the request of a signaller and reporting areas of reportable low adhesion;
- Outputs are usually available showing how the train was handled to assist in educating the trainees.

This can assist drivers in being prepared for all aspects of train operation during low adhesion conditions.

The following RSSB R&D projects provide useful context:

- Managing driver behaviours through adhesion-related information flows (T1156);
- Low adhesion driving policies (T1221).

A1.1.2 Weather Resilience App (WRAPP)

Introduced for the 2023 leaf fall season, the Weather Resilience App (WRAPP) is a newly developed reporting tool that streamlines the reporting of KPIs for the Network Rail Routes by gathering data on operational incidents linked to low adhesion, such as ROLAs, WSTCFs, Station Overruns, and SPADs. The collected data is then securely stored in the Network Rail Seasonal Delivery SharePoint site, which in turn provides inputs for the Autumn Daily Report.

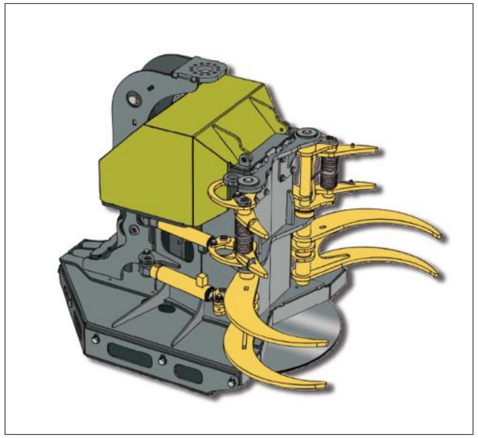
Edition 7, May 2024

A1.2 Infrastructure measures

This section provides further detail on some of the infrastructure measures that are mentioned earlier:

- Vegetation management;
- Leaf fences;
- Removing dead leaves;
- Water jetting;
- Sand based railhead treatment;
- Modified road vehicles;
- Track mounted adhesion modifier dispenser;
- Hand sanding;
- Rail scrubbing;
- Chemicals and organic solutions;
- Track Circuit Assister Interference Detectors.

A1.2.1 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.

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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.

A1.2.2 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. Equally, fences have been known to trap leaves on the line defeating their purpose.

A1.2.3 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.

A1.2.4 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;

- Significant amounts of water are required;
- Water jetting through switches and crossings is subject to local instructions;
- Attention to the set-up of the nozzles is critical.

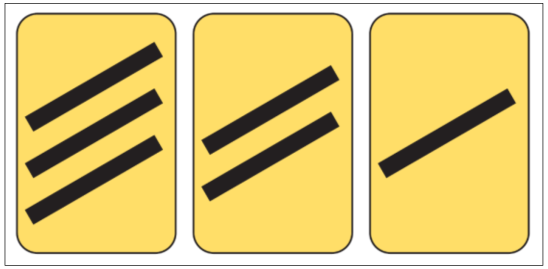
A1.2.5 Sand based railhead treatment

Railhead treatment solutions using adhesion modifiers such as Sandite have been in use for around 45 years and are effective at improving adhesion. One brand 'TG60' is used extensively throughout Britain being dispensed from MPV and RHTTs, whilst static lineside TGA devices and hand-held equipment use an alternative product, 'Electrogel'.

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.



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.**

Adhesion modifier 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 adhesion modifier 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.

Adhesion modifier 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 a friction improver) acts to raise adhesion levels.

Monitoring the performance of the RHTT and the application of water jetting / adhesion modifier laying is critical. The laying of adhesion modifier 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

Edition 7, May 2024

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

- Adhesion modifier 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 adhesion modifier 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 adhesion modifier 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;
- Similarly there have been reports of heated sanding nozzles on some service trains becoming blocked after adhesion modifier has been sprayed back into the nozzles and then being heated to set hard (possibly exacerbated by nozzle angle and position);
- Due to the heavy and viscous nature of adhesion modifier 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, adhesion modifier 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;

- Adhesion modifier 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 these 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.

Laying adhesion modifier from service trains

In the Netherlands, equipment for laying adhesion modifier is fitted to a limited number of passenger vehicles, each capable of laying adhesion modifier 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 cellular radio. The train driver does not interact with the laying system at all. It is controlled automatically by reference to the mapping and GPS systems. Adhesion modifier 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 adhesion modifier on the track at train speeds between 5kph and 70kph. Servicing 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 adhesion modifier at low speeds, and too little at higher speeds.

A similar system (ATUST) 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. Trials continued to around 2021 when increased lineside TGA installation made it less beneficial (appendix A5 item 50).

A1.2.6 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.

A1.2.7 Track mounted adhesion modifier dispenser

Track-mounted static adhesion modifier dispensers, aka 'Traction Gel Applicators' (TGA), are used to provide continuous treatment at locations of particular concern. Developed and supplied by LB Foster Rail Technologies (formerly Portec Rail Products), the dispenser consists of a cabinet with integral 150-litre capacity hopper complete with two peristaltic pumps and drive units, electronic controller, charge regulator and battery. Remote Condition Monitoring (RCM) may also be included allowing operational performance to be monitored using a web portal. A solar panel is provided to charge the battery, which can be mounted on any side of the cabinet or mounted remotely up to 20m away from the unit in areas of low sunlight. The dispenser lays traction gel 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 to activate the pump after a defined number of axle passes which can be varied depending on the level of traffic. The duration of time that the pump is running can also be varied with pre-set minimum of 0.1 seconds up to 2 seconds. The controller also includes a safety pump time out feature which prevents over application.

Lawrence Industries and LB Foster Rail Technologies have developed specific adhesion modifiers for the TGA known as ‘Traction Gel - U5’ and ‘ALLEVIATE®’ respectively. Both are formulated to prevent freezing of the mix down to temperatures of -5°C. The mixture is pumped onto the railhead and then spread along the rails by the passage of the train, up to 100m from the applicator depending on traffic density and train length.

Limitations

- Traction gel 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;
- 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;
- Depending on the product used, performance can be significantly improved by regularly stirring the traction gel to ensure the sand and shot stay in suspension;
- 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 – a remote mounted solar panel may help to mitigate this;
- TGAs are vulnerable to cold and heat – the gel can freeze in extremely low temperatures although LB Foster do offer a low temperature variant of the ALLEVIATE® product which has a freezing point of -16°C;
- 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.

A1.2.8 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 adhesion modifier produced by Lawrence Industries which can be carried to site and laid very quickly on the rails. However, the effectiveness of the application and preventing an excess of adhesion modifier being laid depends on the quality of the application.

Portable Sand / Sandite Dispensers

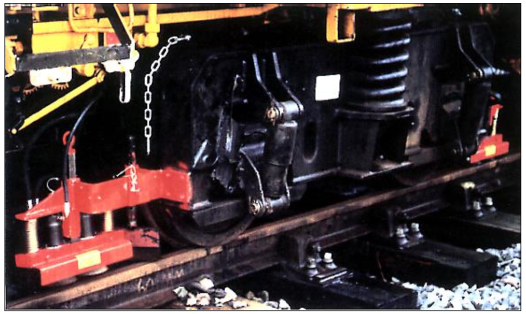
A number of portable sand solution dispensing units are available which are loaded with a small bag of adhesion modifier and run along the rail to dispense it at a measured rate. Various types are marketed by Lawrence Industries, Yardene, Nomix Enviro and Rotamag (adjacent).

Following a small number of serious WSTCF incidents caused by hand application, 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);

- 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.

A1.2.9 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 adhesion modifier 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 around 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.

A1.2.10 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 during station cleaning 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 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.

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.

A1.2.11 Track Circuit Assister Interference Detectors

The Track Circuit Assister Interference Detector (TCAID), developed by BR Research in 1992, was supplied in a sealed weatherproof housing, with cables bolted to the rail web and powered by an internal battery. 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 30 years old.

TCAIDs have two failure modes:

- ‘Right side’ – where the TCAID shunts the track circuit when there isn’t a train on it;
- ‘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.

Replacing track circuits with axle counters would make TCAIDs redundant as axle counters don’t rely on wheel / rail contact, but of course many adhesion problems are on lesser-used routes where the business case is very challenging.

Network Rail is actively tackling TCAID reliability through various initiatives:

- Ensuring that TCAIDs are replaced if life-expired or unserviceable, to reduce the potential for WSTCFs;
- Ensuring that TCAIDs are installed in the right places. A guidance note has been produced, and Network Rail specification RT/E/PS/11762 “Track Circuit Assister Interference Detectors” defines lifecycle requirements from design, safety and environmental to installation, testing and maintenance;
- 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 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 circuit;
- Maintenance is labour intensive;
- They cannot be used on steel sleepers.

A1.3 Rolling stock measures

This section provides further detail on some of the rolling stock measures that are mentioned earlier:

- Wheel Slide Protection (WSP) systems;
- Trainborne Sanders.

A1.3.1 Wheel Slide Protection systems

Requirements

All GB mainline passenger rolling stock must comply with the National Technical Specification Notices (NTSNs) set by the Department for Transport following Brexit, and based on the European Commission's Technical Specifications for Interoperability (TSIs).

The LOC&PAS NTSN (and the TSI before it) requires WSP systems to be compliant and certified to European standard BS EN 15595 "Railway Applications – Braking – Wheel slide protection". This defines requirements for the:

- Construction and testing of WSP equipment;
- Acceptance test conditions which involve track testing of units on low adhesion track, where the low adhesion conditions are created through the application of detergent to the railhead.

It is widely accepted that the adhesion conditions created from such tests are not sufficiently low to replicate those occasionally found in service in GB and other European infrastructure. The first Eurostar train suffered wheel flats on many of its wheels during early testing, despite being approved under the BS EN 15595 test methodology.

Managing Low Adhesion

SCSG

RSSB Guidance Note GMGN2695 "Guidance on Testing of Wheel Slide Protection Systems Fitted on Rail Vehicles" supports BS EN 15595 in GB. It extends the adhesion range defined in BS EN 15595 to values that are lower and which are applicable to GB experience with the wheel / rail contaminant layers generated by leaves in Autumn (see adjacent extract). This extensive and valuable document also sets out guidance for simulators which can assess the performance of WSP systems, in a test house, during low adhesion conditions.

> Supplementary WSP performance testing should be considered for the following reasons:
>
> 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.

System architecture

Contemporary WSP systems comprise three elements: vehicle speed assessment, wheel slide quantification and corrective control of brakes:

- Vehicle speed assessment:
  - If adhesion is able to support all of the forces on the wheelsets of a vehicle, then the wheelsets will roll and not slide. In this case, it is easy for the WSP to determine vehicle speed by using one, or several, signals from the encoders mounted on the axle ends that signal wheelset rotational speed.
  - If adhesion is not good and one or more wheelsets begin to slide, the assessment of vehicle speed becomes much more complex. Low adhesion experts will be aware of speedometers in a driving cab, controlled by the WSP, varying very rapidly as the WSP struggles to determine an accurate value for vehicle speed whilst the train brakes in low adhesion conditions. WSP manufacturers have developed excellent techniques for the determination of vehicle speed when wheels are sliding which, though not perfect, are the very best that is available.

- Wheel slide quantification:
  - The difference between the assessed vehicle speed and the rotational speed of each wheelset allows the WSP to determine if a wheelset is sliding (rotating more slowly than train speed) or spinning (rotating more quickly than train speed). The WSP calculates wheel slide as a proportion of the assessed train speed and, for most modern WSP systems, aims not to eliminate wheel slide but to achieve approximately 15% wheel slide.
  - The goal of 15% wheel slide is set because adhesion is dependent on the amount of wheel slide, and this level usually maximises adhesion when it is low. Additionally, the sliding action of the wheel along the railhead is a contributor to cleaning the railhead, and increasing adhesion for subsequent wheelsets in a train.
  - In low adhesion conditions, electric braking was halted on early traction control systems to avoid damage, and all braking effort came from the friction brake. However, the latest generation EMUs now have electric braking control systems comparable in terms of ability to control slide to the friction brake systems, and electric braking is active in almost all but the most extreme slide scenarios.

Understanding Train Control System Influence on Adhesion Performance

In 2008, RSSB sponsored research by DeltaRail Group into understanding how train control systems influence adhesion performance. 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 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.

RSSB R&D project T545

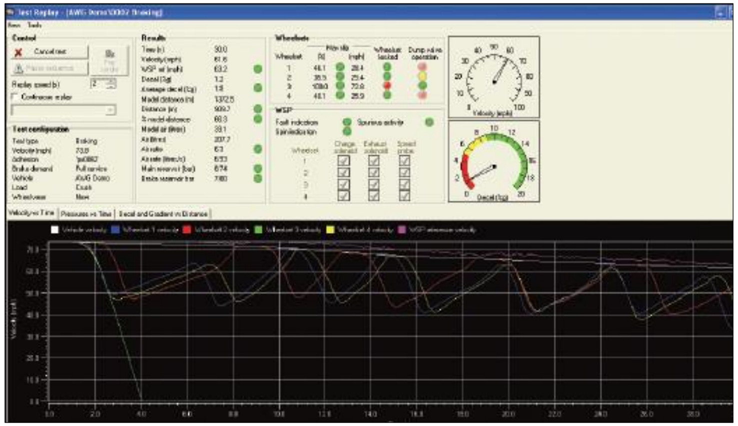
- Corrective control of brakes:
  - The WSP is able to vary brake actuator pressure independently on each wheelset, to try and achieve 15% wheel slide on each wheelset that is sliding. It does this by controlling the valves (dump valves) which feed air into, or out from, each brake actuator. Whilst some older GB rolling stock is fitted with two position dump valves which increase or decrease pressure in the brake actuators, modern rolling stock is fitted with dump valves that have a third position which seals the brake actuator and holds pressure constant. This feature helps to minimise air consumption during low adhesion braking and WSP activity.

- The control of braking in low adhesion is not a black and white process that will always produce the ‘best’ of outcomes. There are important variables such as the level and variability of adhesion on the railhead, the effectiveness of sanding, and the differing pneumatic configuration of different brake systems on different trains, which can all affect the ability of a train to brake when adhesion is low.
- A good brake controller must do more than reduce the stopping distance of a train. It must avoid wheel flats and must not make excessive use of train air, thereby compromising overall braking behaviours. Contemporary WSP manufacturers have all done a fine job in designing their systems, in testing and developing them and – crucially – in optimising their working on each of the individual train types to which they are fitted.

WSP System Optimisation

The standards and guidance listed above provide a general process for WSP optimisation. In principle, such optimisation is achievable via track testing or by test bed simulation. However, track testing all the permutations is immensely difficult, so it is usually supplemented with laboratory based testing on test beds to cover the wide range of scenarios. There is one established test bed and one largely software based system which is still under development:

- WSPER – the established test bed for WSP optimisation that is owned and operated by Deutsche Bahn-ESG. It has sophisticated facilities for testing WSP performance in a wide variety of operating scenarios, and is widely used by brake system manufacturers for optimisation to GMGN2695. WSPER uses software simulations of wheelset braking behaviour, based on adhesion data gathered by BR Research during the 1970s, in conjunction with a manufacturer’s brake control racks and pneumatic brake equipment, and can simulate the braking performance of trains with multiple vehicles and multiple sanders. The use of WSPER to optimise WSP performance on new trains is best practice. It is also capable of



comparing the braking performance benefits of replacing WSP systems fitted to elderly trains with modern WSP equipment (see below). The adjacent image shows a typical output from WSPER, showing how the wheelsets perform under the control of the WSP for a particular adhesion profile.

- LABRADOR is a software system, developed by RSSB and University of Huddersfield (RSSB R&D project COF-UOH-LAB and COF-UOH-74) that uses the most up to date simulations of wheel-rail adhesion, sanders, etc. together with simulations of the significant components of a train brake system. LABRADOR is being developed to simulate a 4-car train in real time and to have a facility to replace its internal WSP system by plugging in a manufacturer’s complete brake control rack. LABRADOR is not yet a tried and tested system, but holds great promise.

Upgrading older WSP Systems

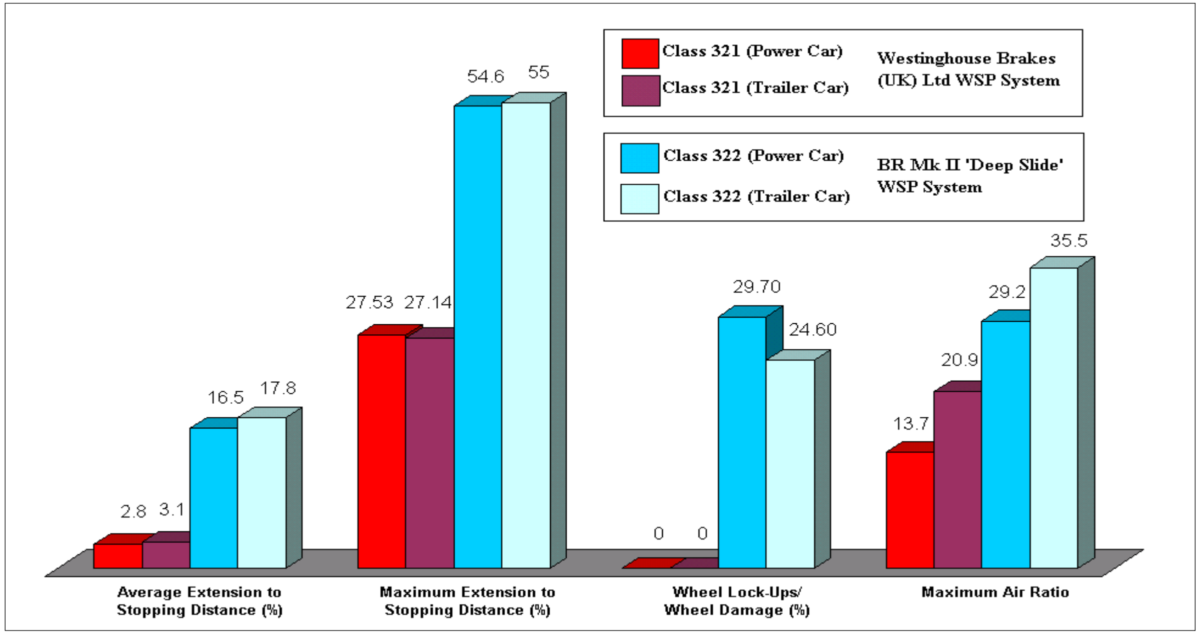
Upgrading older WSP systems to modern, optimised microprocessor controlled WSP systems with adaptive control, can deliver the following benefits:

- 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 WSP 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 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. Knorr-Bremse has since produced a retro-fit WSP upgrade package.

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



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

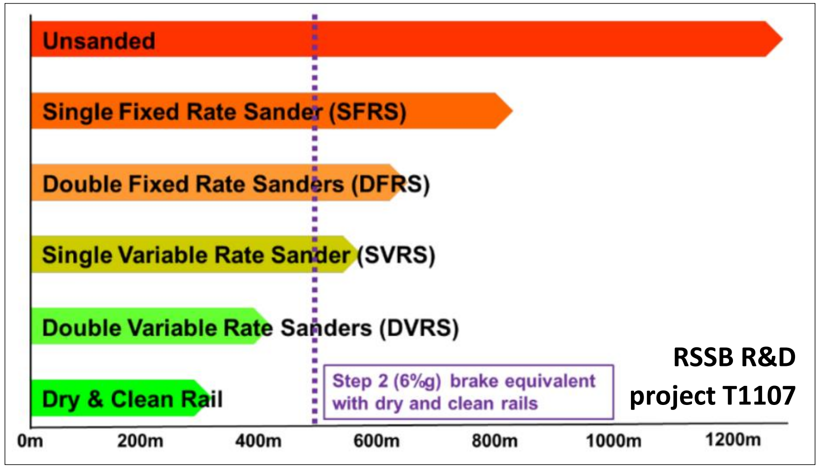
- The average stopping distance extensions were reduced from around 17% to 3%;
- The maximum stopping distance extensions were reduced from 55% to 27%;

- Wheel locking / damage was eliminated from a base of 24% - 30%;
- Maximum air consumption was reduced from 30% - 35% down to 14% - 21%.

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

A1.3.2 Trainborne sanders

The adjacent graph of braking distances from low adhesion track tests (RSSB R&D project T1107) prove that trainborne sanding systems are effective at reducing the risk of low adhesion; confirming findings from Autumn investigations (appendix A7) and incidents such as the collision at Exeter St Davids station in January 2010 where RAIB identified the lack of sanders as a contributory factor.



Requirements

GB requirements are set out in Railway Group Standard GMRT2461"Sanding Equipment" which defines requirements for:

- Sanding systems fitted to trains and sand types;
- Achieving technical compatibility with track circuits;
- Sanding to improve stopping distances in low adhesion conditions;
- Good practice design for sanding equipment;
- Operational practices for the use of sanding equipment.

Originally issued in 2001, the standard has been progressively updated to reflect the findings of RSSB R&D projects T796, T797, T1046 and T1107.

Good practice

All sanders and their installations must conform to GMRT2461. Furthermore, for sanders to work effectively they need to be correctly integrated into their vehicles, and they must be properly maintained. RSSB R&D project T1210 “Good Practice for Sander Maintainability” developed good practice guides for:

- Sander maintenance and replenishment for depot teams to ensure that sander systems deliver sand as designed;
- Integration of sanding systems onto railway vehicles.

There is no benefit in repeating their requirements here, but the following is highlighted with further information available in the good practice guides:

- Fit as many sanders to a train as is practicable, noting the requirements of sander position relative to axle spacing in GMRT2461;
- Fit variable discharge rate sanders rather than fixed discharge rate sanders, preferably using sanders with a continuously variable discharge rate (rather than in steps). This will maximise the amount of sand discharged, thereby maximising the adhesion increase, without threatening track circuit performance;
- The use of a nozzle at the end of the discharge hose increases the amount of sand discharged into the wheel-rail nip;
- Sanders should operate in all brake demand levels;
- Sanders should be active in all units when coupled together into a train;
- Sanders can be fitted to trains with fewer than eight wheelsets (even single vehicles) ahead of the leading axle, as set out in GMRT2461;
- Sander maintenance is a safety critical activity and should have equal importance to brake system maintenance. Good practice in sander maintenance includes:
  - Regular checks of sand level in the hopper, recording sand usage of different sanders and analysis to pick out bad actors for correction – consider installing automatic sand level monitoring and reporting systems;
  - Filling sand hoppers with clean dry sand;
  - Measuring sand discharge rates and correcting where necessary (in tests by BR Research, sanders discharging sand at 1.5kg/minute provided little or no adhesion benefit relative to sanders discharging at 2.0 kg/minute);

- Checking that the sanders work when the WSP requests it;
- Checking that the sander discharge is accurately directed at the wheel-rail nip;
- Compliance with the relevant COSHH information for handling sand.

Note also:

- The RSSB R&D described in section 6.2, which demonstrated that the reduction in low adhesion SPAD risk provided by sanders far outweighs the risk from WSTCF caused by sand contamination.
- The incident at Stonegate in Kent in autumn 2010 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 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.
- Due to concern about the long-term infrastructure effect of sanding at very low speeds over points and crossings, GMRT2461 requires drivers to have the capability to inhibit automatic traction sanding where provided. On most modern units, drivers can only apply sand if there is wheel spin occurring, which prevents unnecessary sanding.

A1.4 Information measures

This section provides further detail on some of the information providing measures that are mentioned earlier:

- On-Train Data Recorders (OTDR);
- London Undergound's Adhesion Controller's Condition Assessment Tool (ACCAT).

A1.4.1 On-Train Data Recorders (OTDR)

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 Network Rail of areas where railhead treatment is required.

Every train that operates on the mainline now carries an OTDR, a 'black box' recorder. OTDRs 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.

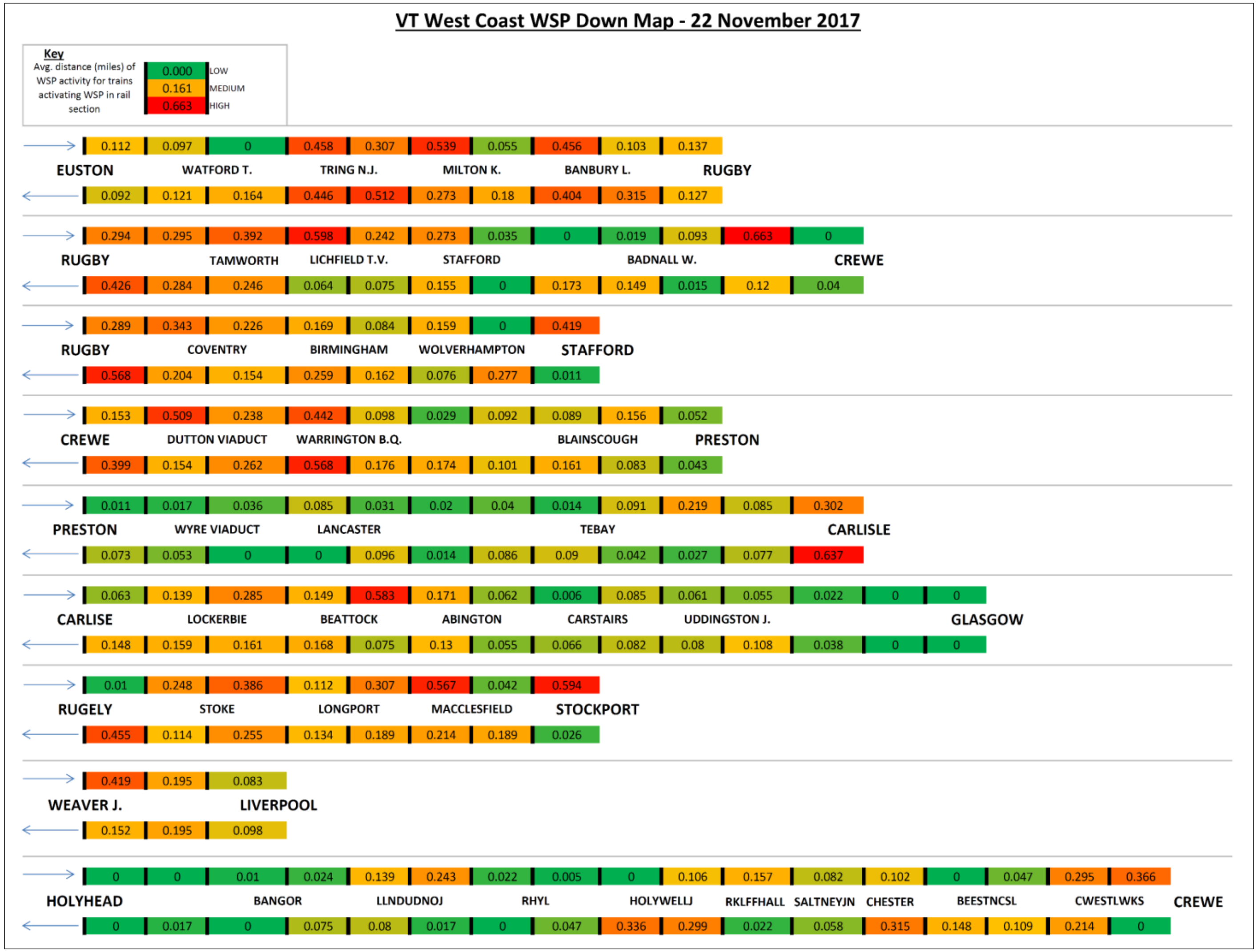
A good example of the use of OTDR data came from Virgin Trains who extracted WSP data from their Pendolino (Class 390) and SuperVoyager (Class 221) trains on the West Coast Main Line. Data was downloaded every weekday for routine analysis during the leaf fall season. The OTDR data was used to investigate driver and train performance / behaviour, looking for consistency and the infrastructure state. In addition, the data was 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 were via Wi-Fi, at the end of a journey or at any other time when the train was stationary (to avoid file corruption). The train operator was able to access the data almost in real-time following an event they wished to look at. Files were exported to a bespoke OTDR Auto-Analysis Tool developed by Virgin Trains. The analysis could take from a few seconds to many hours depending on the complexity of the analysis required. TASS balises provided an accurate position reference source. The alternative was 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 overleaf.

Edition 7, May 2024



Edition 7, May 2024

Reports were sent out each day, based on 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 was 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:

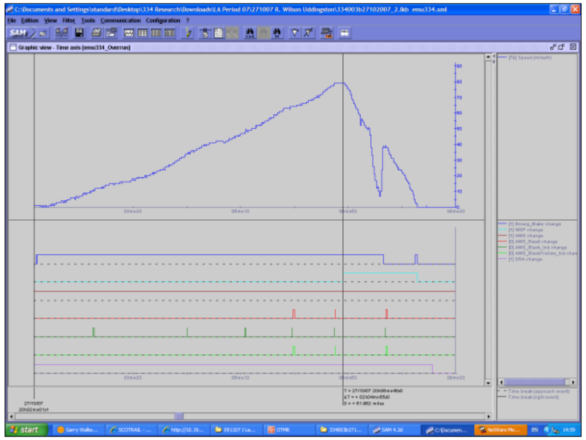
- Collating locations and details of WSP events over a specified distance threshold and sharing with Network Rail to inform railhead treatment;
- Analysing data from problem sites to establish likely conditions on the line before and after railhead treatment;
- Validating and improving route forecasts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

Edition 7, May 2024

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’ for the uninformed:



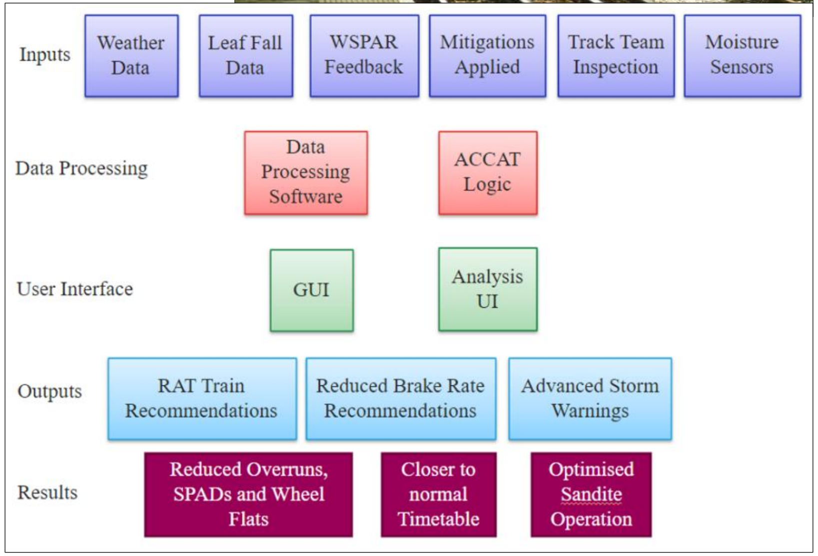
- The speed output shown on the OTDR data may be affected by the action of the WSP controlling the wheelsets in ‘slip’ (the wheels are turning slower than the train’s forward speed). This can be seen in the adjacent output. The troughs in the speed trace represent the wheelset speed (i.e. of the wheelset 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.
  Virgin Trains overcame this problem by isolating the brakes on the leading axle (where the speed was recorded) so that it was free to roll and hence record the true forward speed of the train. This is good practice for operators with fixed formations where braking capability allows, unless there is 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.

- 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 wheel spin or wheel slide.

A1.4.2 London Underground’s ACCAT

Originally developed over a number of seasons for the Central Line, the ACCAT (Adhesion Controller’s Condition Assessment Tool) is now increasingly used on the Circle, Metropolitan, District and Hammersmith & City lines as well. It is deployed on sub-surface lines where Automatic Train Operation (ATO) is in operation.

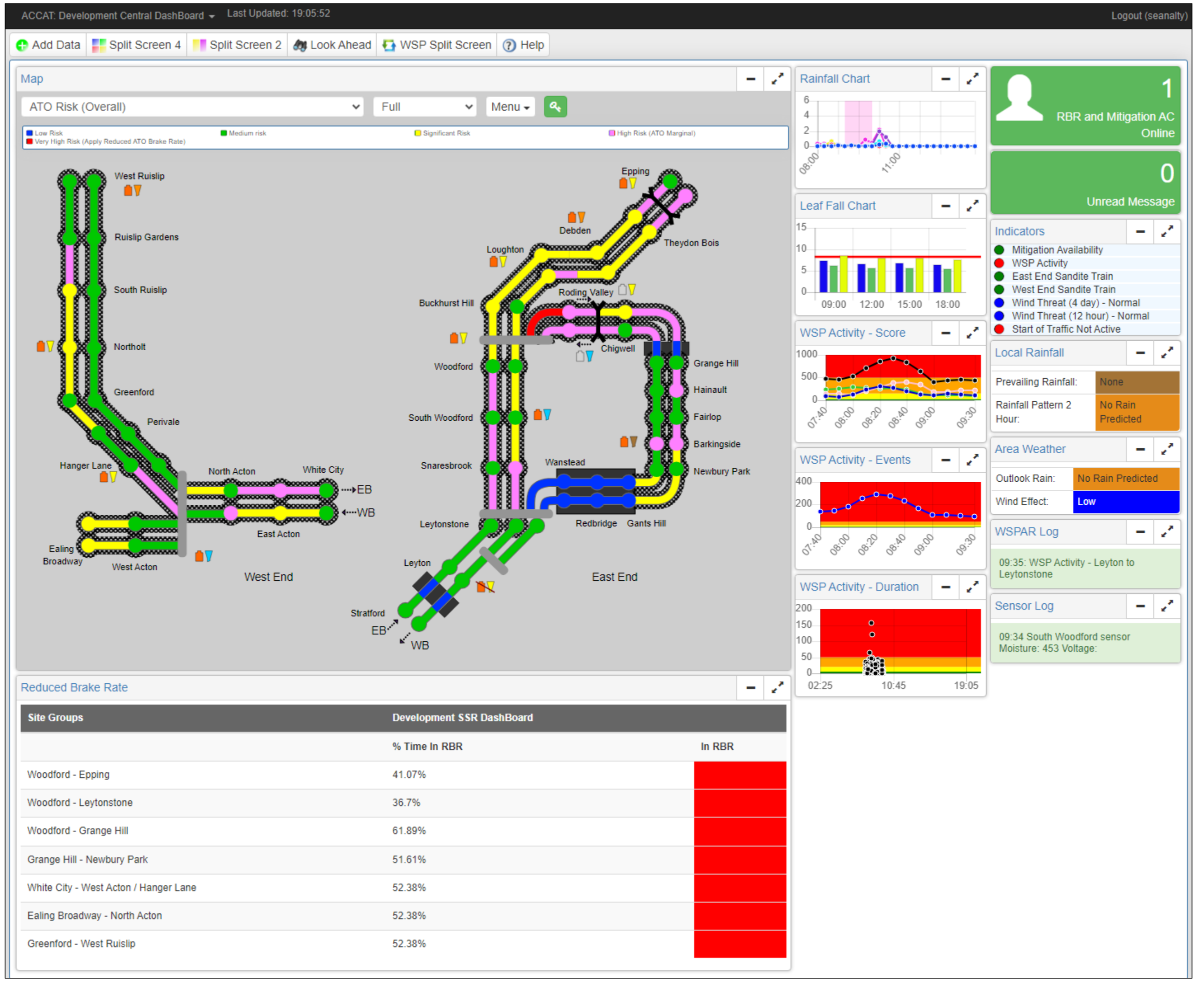
ACCAT uses inputs from various sources (adjacent) to determine the risk of contamination; largely based on leaf fall prediction, rainfall information and moisture presence from railhead sensors. The risk of contamination together with service information and knowledge of current conditions and mitigations, is used to determine whether the ATO should reduce its acceleration and braking rate.



The 2024 ACCAT screen is shown overleaf. 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 rate is currently implemented, based on the predicted conditions. In the panel to the right, WSP activity can be seen and it has been high for a

Edition 7, May 2024

significant period justifying retention of the reduced rate. ACCAT can also predict up to 6 hours ahead. An Adhesion Management System (AMS) based on ACCAT was investigated by AWG for the mainline but, in its present form, the business case was only viable for short high intensity railways.



A1.5 New and emerging measures

This section describes measures that are currently being developed. The majority are listed in the 'GB Approach' (section 2.5) which considers them as 'new and emerging' because they are not yet proven, although some are close.

Many different organisations can lead the development of new control measures, including industry bodies delivering research such as RSSB, Network Rail and UK Rail Research and Innovation Network (UKRRIN) universities, as well as private industry.

SCSG actively encourages new control measures to be developed but cannot assume responsibility. However:

- SCSG's 'GB Approach' does encourage train operators and rolling stock maintainers to provide reasonable support, appropriate to their organisation, with trialling unproven measures;
- SCSG offers support and guidance to organisations developing new control measures. SCSG can help with the authorisation process and will verify, but cannot authorise, those which are proven and practical;
- Industry endorsed test processes that will facilitate industry acceptance are described in section A2.

The following sub-sections briefly describe various new and emerging measures. It is by no means a complete description and the latest status is available from the organisations involved. They are listed in no particular order:

- Cryogenic railhead cleaning;
- Plasma railhead cleaning;
- Laser railhead cleaning;
- Water/abrasive railhead cleaning;
- Enzymatic pre-treatment for railheads;
- Interflon LeafGuard OTR for railheads;
- Double Variable Rate Sanders (DVRS);
- Water-Track;
- Rail-Traction;
- Applying sand alternatives to reduce WSTCFs;
- Wheel flat protection for freight wagons.

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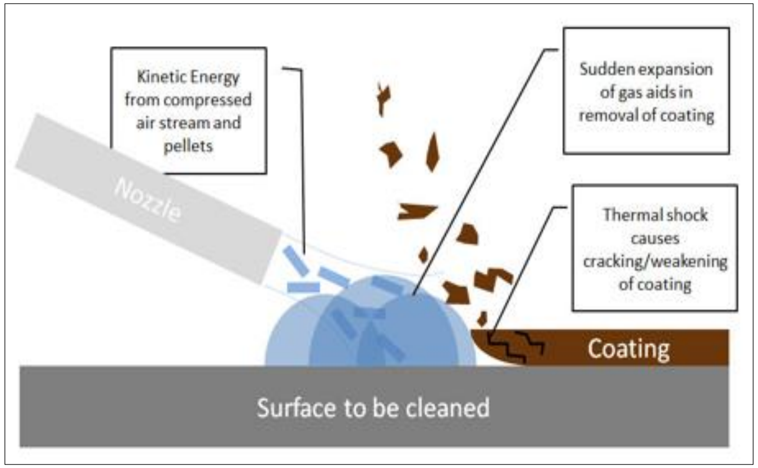
A1.5.1 Cryogenic railhead cleaning

The University of Sheffield and Cryo Technologies Ltd have adapted an existing industrial cleaning process for use on the railway. Cryogenic Railhead Cleaning uses a jet of dry ice pellets fired at the railhead to remove contamination utilising the:

- Kinetic energy of the dry ice pellets hitting the railhead;
- Expansion from the instantaneous conversion of the pellets to gas;
- Thermal shock from cold to hot that accompanies this change in state.



The dry ice pellets are fired at the railhead at significantly lower pressure than the pressure of water from the RHTT. The equipment is therefore much more compact and can be fitted under a service train offering several benefits:

- It is more cost-effective than operating a dedicated RHTT;
- It avoids pathing issues during the day and possession clashes when operating at night;
- A service train can treat a line of route several times per day, seven days per week, preventing the build up of contamination.

The University of Sheffield have purchased two Class 142 which have been certified for main line operations. Both units have been fitted with Cryogenic Railhead Cleaning equipment and are being utilised as demonstrators on the mainline.

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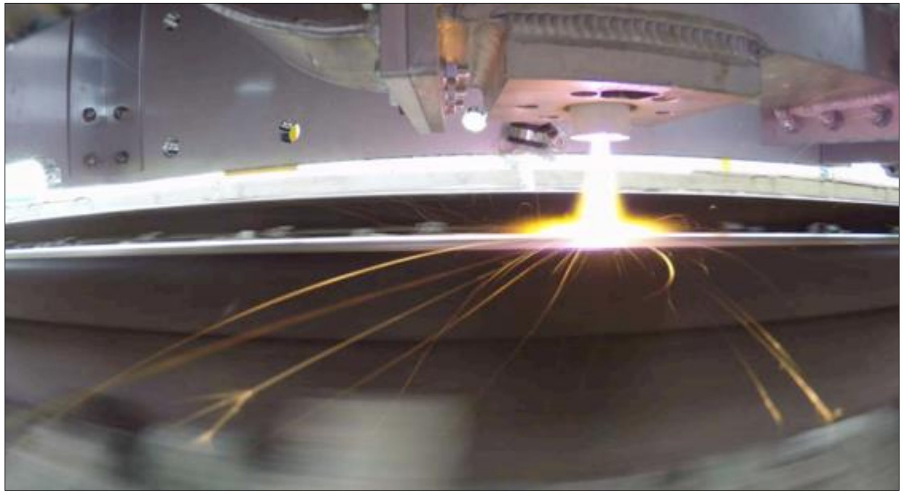
A1.5.2 Plasma railhead cleaning



Following a UK Government and RSSB call for rail solutions aimed at predictable and optimised braking with the goal of easing autumnal challenges, the developers of PlasmaTrack originally considered utilising microwaves as a solution to clean the tracks to remove the leaf layer. However, it became apparent during the feasibility study that the technology was not robust enough for the railways, so the developers switched to a plasma solution called 'PlasmaTrack'.

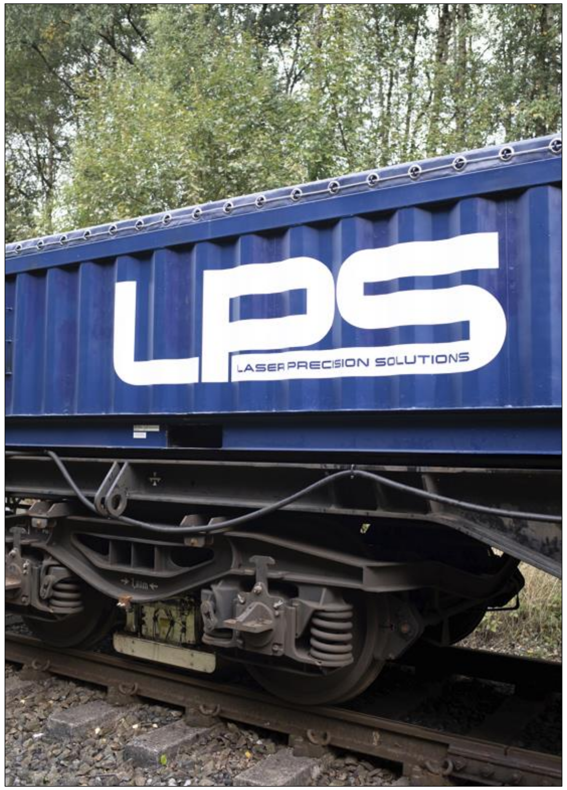
PlasmaTrack works by passing high voltage Direct Current (DC) through compressed nitrogen which is easily extracted from the surrounding air. This is converted into a plasma jet of high-energy electrons and ions, which is then delivered to the rail head at speeds of up to 60mph (95kph) and temperatures of around 700°C.

With a single pass, the plasma jet thermally removes the compacted leaf layer and returns the track to a clean, dry, and uncontaminated state capable of supporting summer braking conditions.

Trials have been carried out in Wales and Scotland using PlasmaTrack mounted on a Road Rail Vehicle. In Autumn 2022, Network Rail carried out track testing with a Multi-Purpose Vehicle on the East Lancashire Heritage Railway. The tests concluded that further optimisation was required.

Edition 7, May 2024

A1.5.3 Laser railhead cleaning



Laser Railhead Cleaning uses a focused intense energy of laser beams (laser ablation) to remove contaminants, debris, rust, and other unwanted materials from the surface of the rails.

The use of lasers to clean contamination from the railhead was first trialled by Network Rail in the early 2000s. The early trials were abandoned over the ability to target the laser with sufficient accuracy to clean the contact band, and being able to provide sufficient power.

After further development work, laser railhead cleaning was trialled on a test train in the Netherlands in 2015. The results, however, were disappointing with effective cleaning being limited to a maximum speed of 13kph.

The system has now been further developed by Laser Precision Solutions and has been in service on a dedicated train operated at 25mph on the Long Island Railroad since 2018, with a second train added to the fleet in 2021.

A 60mph capable laser railhead cleaning train was piloted on the Metro North Railroad in Autumn 2022 and claimed a 40% reduction in wheel slip incidents and a $1.6million saving to the rail administration. Two 3kW lasers are mounted on each side of the train to give a 3cm cleaning band. New 60mph LaserTrains have recently been launched with Keolis (Boston), WMATA (Washington) and a 25mph one with Staten Island Railways.

In Autumn 2022, a wagon fitted with laser railhead cleaning was trialled on the East Lancashire Heritage Railway by Network Rail. The trial utilised existing contamination as well as an artificially created contamination layer. The tests concluded that further optimisation was required.

A1.5.4 Water / abrasive railhead cleaning

Being developed by LNT Solutions and ANT AG, TrackJet is a new technology aiming to provide a more efficient way of removing the 'hard-baked' leaf contamination from the railhead during the autumn season. It maximises the power of pressurised water by engineering it to encapsulate a hard, sharp abrasive particle. The resulting high energy particles pierce the leaf film and the attendant water dissipates the loosened debris from the railhead, leaving it clean and with restored good adhesion.

This technology is expected to deliver both performance and environmental benefits:

- Performance benefits from the abrasive jetting system delivering greater force than water jetting to remove leaf contamination, which results in a cleaner track;
- Environment benefits because the potable water required is reduced by 80 – 85% and the diesel required to haul the treatment load is thus significantly reduced, although the train will need to carry abrasive consumables as well.

An off-lease Class 153 passenger vehicle has been retrofitted with TrackJet hardware to convert it into a Rail Head Treatment Train (RHTT). This vehicle has now completed extensive test track trials at speeds of 60mph that prove it has the ability to remove 'baked-in' black leaf contamination and restore railhead adhesion to the values required for normal railway timetabling.

Before jetting at 60mph

After jetting at 60mph

Edition 7, May 2024

Managing Low Adhesion

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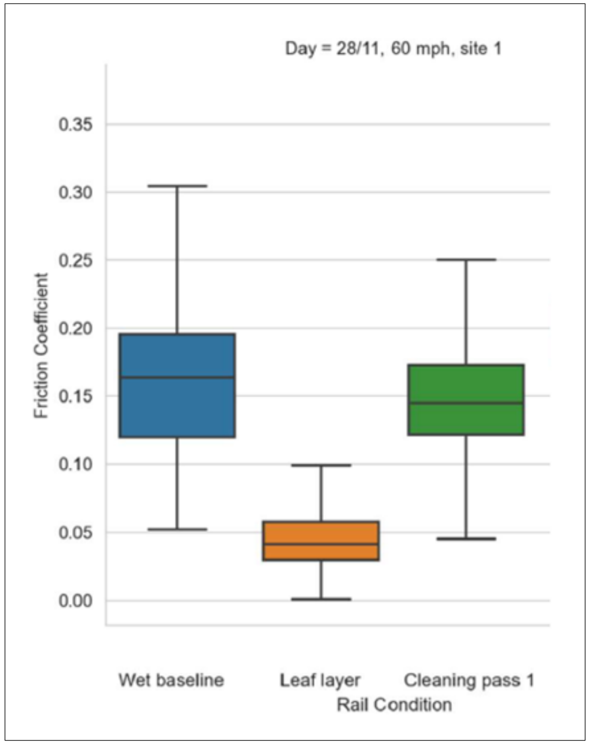
The adjacent graph illustrates the restoration of railhead adhesion to operating levels that deliver good braking and traction. Tests over a two-week period have demonstrated repeatable results.

Tests have shown that the significantly reduced water requirement of the system results in no over spray that may adversely affect the adhesion on the adjacent running rails. The jetting system was proven also not to compromise rail lubricant applications, AC/DC track circuits, or S&C.

The vehicle is mainline compliant and set to operate in Autumn 2024 in place of a water-jetting RHTT. Its operational running time is twice as fast as that of an MPV RHTT and thus will facilitate more extensive and dynamic circuit planning.



A1.5.5 Enzymatic pre-treatment for railheads

In 2016, RSSB conducted a 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. More classic, cost-effective chemical solutions include hydrogen peroxide, and organic solvents such as methanol and weak alkalis.

In 2023, RSSB work with the Universities of Sheffield and York on leaf composition and evaluating enzyme treatments (RSSB R&D project COF-G24-01) involving full-scale tests at the Quinton Rail Technology Centre's test track, found that:

- Analysis of fallen leaves from seven common tree species showed that the major components are cell wall polysaccharides (30-40%) and polyphenols (20-30%), with little variation in proportion by species;
- In the transition from crushed leaves to railhead film, there is a decrease in the polysaccharides and a sharp increase in polyphenols, and this was correlated with a marked increase in iron (from the railhead);
- A number of enzymes were identified as potential candidates for degrading the molecular structures of the leaves and leaf film material with promising findings.

Further lab-based testing assessed the impact that enzyme treatments might have on adhesion of crushed leaves and railhead films. This indicated that when a leaf layer is treated with an enzyme solution, for an appropriate amount of time, it can improve its adhesion performance. It also indicated that lineside leaves could potentially be treated prior to entrapment in the wheel / rail interface.

Further evaluation of leaf enzyme treatments is progressing (RSSB R&D project COF-G24-02).

For information on the chemicals and organic solutions already being deployed by Network Rail see appendix A1.2.10.

A1.5.6 Interflon LeafGuard – Clean OTR for railheads

Interflon LeafGuard – Clean OTR is a powerful biodegradable cleaner / deoxidiser developed to quickly remove organic leaf contamination and oxidisation from the railhead and, hence, reduce adhesion issues and risk of WSTCFs.

The cleaner has a quick activation time (1-2 minutes). There is no need to rinse off with water or wipe as the product self-cleans. It is reported to leave a micro layer that re-activates with rainwater and moisture helping the surface to stay cleaner for longer.

The product is also reported to be very effective as a preventative measure. If applied to a clean railhead, it will help to keep it clean. Proactively treating railheads before they become a problem will save time and effort later if the product is applied regularly.

It is reported that the product does not damage steel, rubber, plastic or reflective coatings so will be safe around cabling and insulators / pads and signage.

It can be diluted with water dependent on the level of contamination.

Converted Sand Pram rail head applicator (Blade)

Interflon backpack sprayer with a long lance

Edition 7, May 2024

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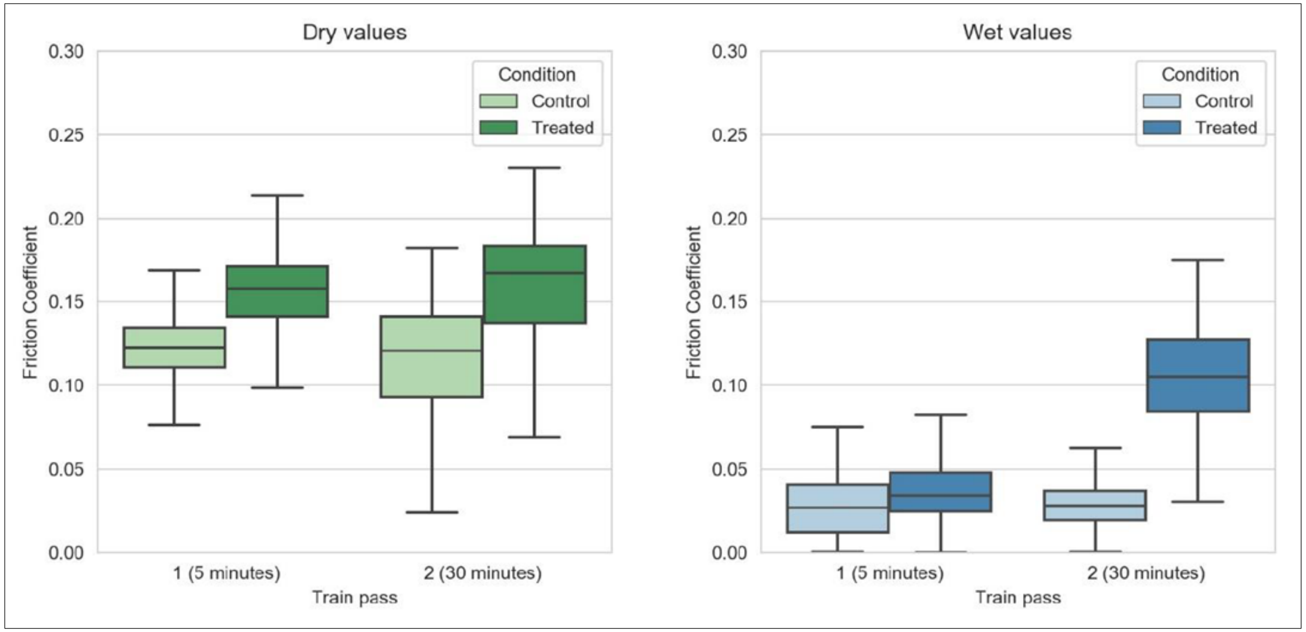
During autumn 2023, Network Rail applied undiluted Interflon at test sites that were heavily contaminated with a black leaf layer:

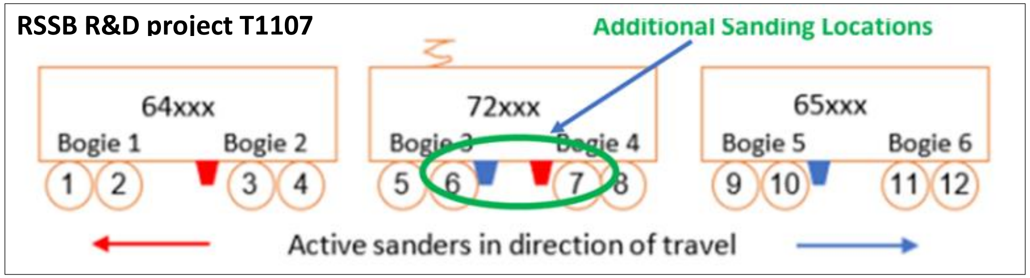
- Soon after application, the leaf layer discoloured turning from black to brown/green, and began to weaken the bonding between organic material and the rail steel substrate;
- There was no visible top-of-rail carry down when the site was inspected after testing. Some excess product appeared to be carried on the gauge corner by wheel passage, approximately 5m after three train passes;
- When there was no mechanical action (including wheel passes) or water washing, the detached leaf layer remained on the railhead and continued to produce low adhesion. However, this layer could be wiped or washed away easily;
- During testing, vehicle air flow picked up lineside fallen leaves and deposited them on the railhead.

The graphs below depict the levels of adhesion on dry and wetted rails at one of the test sites. The central line indicates the median, the box the 25th and 75th percentiles, and the 'whiskers' the minimum and maximum values.



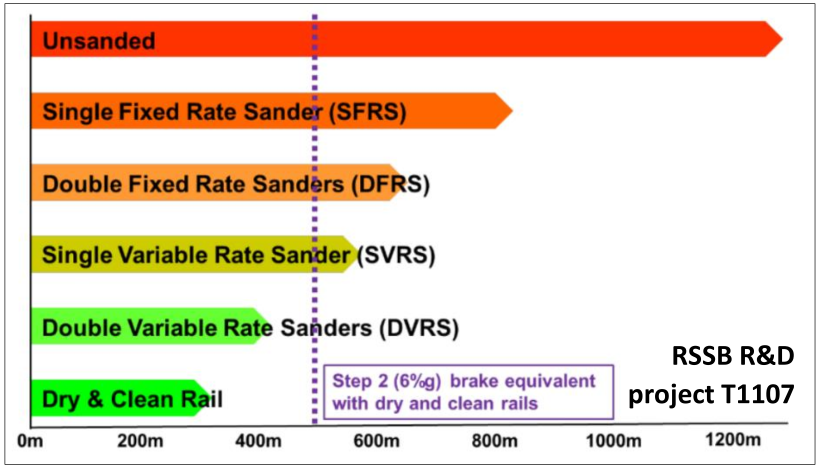
A1.5.7 Double Variable Rate Sanders

Most GB mainline trains are fitted with a single, fixed rate sander, which sprays sand at the wheel / rail interface of the third axle at a rate of typically 2kg/min (section 5.2.2). The sanders activate in response to Wheel Slide Protection (WSP) activity, or after the driver presses the sander button. Variable rate sanders deliver sand in a speed-dependant manner, meaning sand delivery is optimised at both high and low speeds.



As the name suggests, Double Variable Rate Sanders (DVRS), have a second sander, which on a three-car unit is ahead of the seventh axle. The sanders spray sand at a higher rate of up to 6kg/minute in Emergency. A Single Variable Rate Sander (SVRS) is also available for two car multiple units.

DVRS was first tested on a test track in 2017 using paper tape to simulate low adhesion (RSSB R&D project T1107), where it was found to deliver braking almost as comparable to a clean dry rail. DVRS can halve stopping distances on a four-car train compared to single fixed rate sanders (see adjacent graph of braking distances).



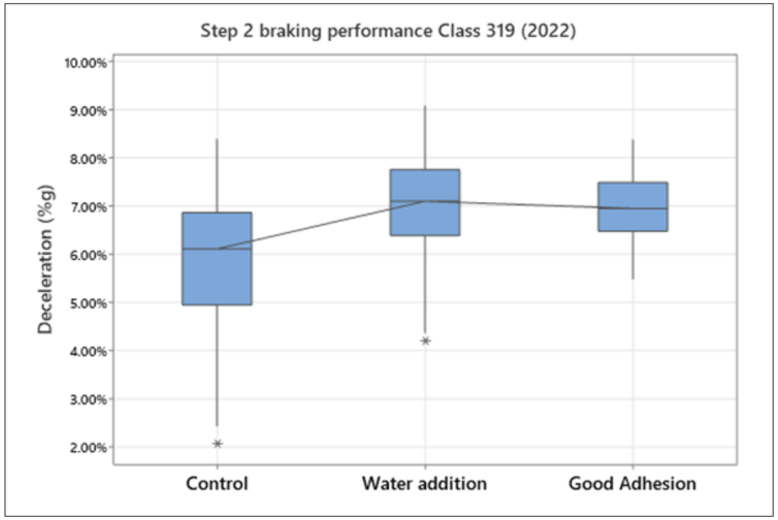
As of early 2024, DVRS and SVRS is being fitted at Northern Trains Limited (DVRS), ScotRail (DVRS) and South Western Railway (SVRS).

A1.5.8 Water-Trak

In the 1970s, British Rail Research demonstrated that the worst low adhesion conditions were encountered in damp and dewy conditions and that adhesion improved as the railhead became wetter. The findings from these studies and observations of the positive effect of heavy rain on railhead contamination encouraged researchers to test the effect of water in the real world.

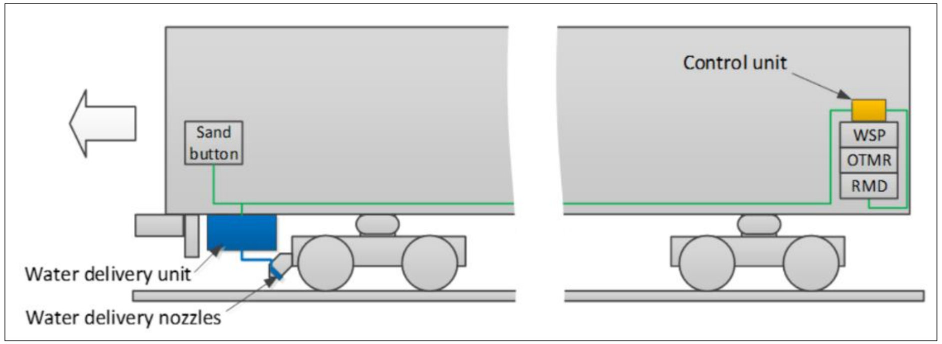
In 1979, trackside water spraying equipment was tested at Bearsted Bank (near Maidstone, Kent). Rail adhesion values were collected for a sprayed section of the track and a 'control' section, which remained untreated showing a statistically significant improvement in adhesion with water spraying. While the evidence from these tests confirmed the benefits of trackside spraying, it has never been implemented on the GB rail network, perhaps due to concerns about the cost and complexity of maintaining such a solution.

In 2013, the original research was rediscovered as part of a study commissioned by RSSB and a solution using service trains was proposed. A series of mainline trials with Northern trains over the last three autumn seasons has shown the benefits of this solution. Improved braking has been demonstrated in low adhesion conditions as shown in the adjacent graph.



Controlled water addition is now being commercialised under the Water-Trak brand. The Water-Trak system comprises a water tank, pump, jetting nozzles and associated pipework which is fitted underneath a service train. The system sprays water, at a pressure of around 7bar, onto the railhead ahead of the first axle in response to Wheel Slide Protection (WSP) activity on the train.

Water-Trak is now being fitted to all the Northern Class 170 units (see adjacent schematic of the installation).



A1.5.9 Rail-Traction

Rail-Traction™ is a specially formulated aggregate that has been developed as a direct replacement for the sand used in trainborne sanders or applied manually to the railhead, as a mitigation for wet rail conditions. As with conventional sand, adhesion increases when the aggregate enters the wheel / rail contact patch however, it is reported, that:

- The key difference with Rail-Traction™ is that it has a significant drying effect on the railhead due to hydroscopic properties;
- The University of Sheffield conducted testing that proved this drying effect results in the trailing wheelsets having a dry contact point at braking, thereby reducing braking distances.

The formulation has been developed by Hoben International Limited supported by South West Trains and Network Rail.

Rail-Traction™ has most recently been trialled on Network Rail Anglia and Scotland routes being deployed by hand (not by train). The Anglia Autumn 2023 trial was not yet conclusive, and further testing is planned for Autumn 2024.

Edition 7, May 2024

A1.5.10 Applying sand alternatives to reduce WSTCFs


RSSB R&D project COF-UOS22-03

Informed by work done by the University of Sheffield (RSSB R&D project COF-UOS-03 and COF-UOS22-03), LB Foster and LNT Solutions are developing an alternative sand-like aggregate that is electrically conductive to reduce the risk of Wrong Side Track Circuit Failures (WSTCFs).

Following earlier work, candidate products were evaluated in 2023 by track tests with a Class 142 at the Wensleydale Heritage Railway. The aim was to address remaining queries, including the:

- Impact of conductive particles on Insulated Block Joint (IBJ) performance;
- Effects on contamination in track tests, encompassing track circuit operation and braking.

In clean conditions, conventional rail sand caused track circuit issues, whereas two products did not exhibit such problems. However, the application of leaf material on the railhead caused a loss of train detection. Braking tests conducted on contaminated rail suggested that all adhesion materials mitigated leaf contamination.
Further testing is currently being considered:

- High-speed braking tests on a South Western Railway Class 158 at RIDC Tuxford;
- Braking tests planned with Northern Trains on the Monk Bretton branch.

Based on the outcomes of the braking tests, a deviation to Railway Group Standard GMRT2461 “Sanding Equipment” could be submitted, to enable a trial to be undertaken on the GB mainline in Autumn 2024.

A1.5.11 Wheel flat protection for freight wagons

Lack of electrical power, not to mention cost pressures, have meant that freight wagons are not usually fitted with WSP systems. However, Knorr-Bremse have developed a Wheel Flat Prevention system called Sentinel for a 'self-powered digital wagon' developed by VTG called iWagon.

iWagon has the following features:

- Continuous monitoring of the brake system to detect deterioration of performance;
- Detection of axle lock;
- Monitoring the wagon's ambient temperature and hand brake status;
- Axle end generators to produce the electrical energy required for the above.

A trial was initially undertaken during October 2023 with three wagons operating within the Tarmac flow based out of Dunbar, travelling to Aberdeen and Leeds as well as Inverness. The rake comprised one iWagon in between two monitoring wagons. Four journeys covered 750 miles in total, and the trial was cut short due to significant wheel slides occurring on the monitoring wagons which required new wheelsets; the active iWagon operated as expected and incurred no wheel damage.

As of February 2024, nine iWagons are operating on the GB mainline within the Hanson (Clitheroe to Mossend) and Mendip Rail (Whatley / Merehead to Avonmouth and West Drayton) flows.

Mass production lines for the iWagon are being built and are planned to go live from mid-2024.

A2 Testing solutions to low adhesion

This section documents ARG's recommendations for third parties to adopt when testing processes that will improve wheel / rail adhesion. Whilst the requirements are not mandatory and the customer will be the final arbiter, these recommendations are the industry's agreed way of evaluating new processes so compliance with them will facilitate industry acceptance of the new process.

It is important to note ARG's view that clean rails do not necessarily provide good adhesion and that processes which are able to clean rails should not, without the testing and reporting identified in this document, be assumed to improve adhesion.

The requirements are extracted from the paper "ARG Recommendations for Good Practice in Low Adhesion Testing" Version 1.7 which was endorsed by ARG in June 2023. A review of its usefulness is planned mid-2024.

A2.1 Recommendations

ARG believes that any testing of low adhesion improvement processes must lead to an unambiguous argument that the process will improve adhesion in a dependable way. Such an argument must be based upon good experimental practice. The following does not attempt to define good experimental practice as there are many other publicly available sources which do this. However, the following sections pick out key elements of good experimental practice which are important to ARG.

It is important to note that ARG sees no value in processes that fail to demonstrate improved adhesion from a low adhesion start point. A visual improvement in 'cleaner' wheels or rails has little or no value.

Formulating a hypothesis

Good experimental practice requires that a hypothesis is formulated which the trials will prove or disprove. This is not 'rocket-science', a likely hypothesis in work of interest to ARG is that by following an identified process, wheel / rail adhesion will be improved from a low adhesion start point.

Process Description

ARG recommends that any test description should have enough detail to allow an independent party (with no prior knowledge of the test process) to replicate the tests and produce similar results to those that the process owner might obtain.

A key aspect of demonstrating adhesion improvements is to carry out test work on low adhesion layers which are well bonded either to rails or to laboratory test pieces. There are several established techniques that have been shown to deliver such adhesion layers; these are listed in appendix A2.2. ARG recommends that test work should make use of techniques which closely follow the work listed in appendix A2.2 or which might use techniques which have been shown to be similarly effective. The test procedure should include a method to demonstrate that the adhesion layer is sufficiently bonded to the rail.

ARG recommends that test work for full scale railway operation makes use of vehicle or train deceleration in braking as a clear indicator of adhesion, when adhesion is low. Examples of full-scale adhesion trials which do this and which have employed well-bonded, low adhesion layers include work from RSSB for relatively high-speed testing (Ref 1 in appendix A2.2); and from University of Sheffield for modest speed testing (Ref 2).

ARG recommends that laboratory based low adhesion testing such as twin disc, low speed wheel on rail, high speed wheel on dynamometer, and high-pressure torsion rig testing should follow the methodologies described in documents in appendix A2.2. These laboratory test techniques employ well-bonded low adhesion contaminant layers. ARG recommends that any other laboratory test techniques should be based on a proven ability to employ well-bonded low adhesion layers.

Further guidance is provided in industry documents:

- GMGN2642 “Guidance on Wheel / Rail Low Adhesion Measurement”;
- GMGN2643 “Guidance on Wheel / Rail Low Adhesion Simulation”.

ARG expects that all test activity will comply with the relevant safety management requirements.

Edition 7, May 2024

Test Work Results and Reporting

ARG recommends that:

- A report is produced which fully describes the testing that was undertaken and the methods used to generate low adhesion conditions, and includes the results from the testing;
- Results are presented in a document that is widely available to industry and which provides a logical trail that demonstrates whether or not the test hypothesis has been proven;
- Results are recorded and analysed to show the benefits, and any dis-benefits, experienced during testing;
- Results are analysed to quantify adhesion increases shown in the test work, relative to the low adhesion start point for testing;
- Variability in adhesion benefit during testing should be quantified and, where practicable, explained. ARG believes that repeatable test results are very important for industry to have confidence that a particular process will bring benefit to the railway;
- Full scale railway tests should be undertaken for a range of ambient conditions on the rail, as leaf-based adhesion is currently understood to be affected by moisture, temperature etc.;
- Laboratory tests should be undertaken for a wide range of test parameters, such as contact stress, speed, slippage etc. as described in the appendix A2.2 reference documents;
- Analysis of results is supported by a third party with no commercial link to the process owner.

A2.2 ARG endorsed trials methodologies

Descriptions of these established on-track and laboratory test methodologies (including the formation of low adhesion and well bonded contaminant layers) have been published and are available below:

Ref 1: Rail Safety and Standards Board trial of sander configuration and sand laying rates

- Purcell L, Lightoller A, 2018, "Trial of Sander Configurations and Sand Laying Rates", Rail Safety and Standards Board, RSSB Ref: T1107;
- Purcell L, 2017, "RSSB T1107 Sander Testing: Dynamic Testing at RIDC Melton Method Statement", RSSB Ref: T1107, Ricardo Rail Ref: 753073MS02.

Ref 2: University of Sheffield testing of cryogenic cleaning at Long Marston

- Lanigan J, Krier P, Buckley-Johnstone L, White B, Ferriday P, Lewis R, 2022, "Field Trials of a Methodology for Locomotive Brake Testing to Assess Friction Enhancement in the Wheel/Rail Interface using a Representative Leaf Layer", Journal of Rail and Rapid Transit, Proceedings of the IMechE, Part F, Vol. 235, pp1053-1064;
- Krier P, White BT, Ferriday P, Watson M, Buckley-Johnstone L, Lewis R, Lanigan JL, 2021, "Field Trials of Cryogenic Cleaning using a Road-to-Rail Vehicle: Assessment of Effect on Rail Head Cleaning Effect through Train Brake Tests", Proceedings of the Institution of Civil Engineers, Civil Engineering, Vol. 174, No. 4, pp176-182.

Ref 3: University of Sheffield twin disc testing

- Lewis SR, Lewis R, Cotter J, Lu X, Eadie DT, 2016, "A New Method for the Assessment of Traction Enhancers and the Generation of Organic Layers in a Twin-Disc Machine", Wear, Vol. 366-367, pp258-267;
- Ishizaka K, White B, Watson M, Lewis SR, Lewis R, 2020, "Influence of Temperature on Adhesion Coefficient and Bonding Strength of Leaf Films: A Twin Disc Study", Wear, Vol. 454-455, 203330.

Ref 4: University of Huddersfield wheel on rail dynamometer testing (undertaken on the HAROLD (Huddersfield Adhesion and Rolling Contact Dynamics) test rig)

- Lewis R, Trummer G, Six K, Stow J, Alturbeh H, Bryce B, Shackleton P, Buckley-Johnstone L, 2023, "Leaves on the Line: Characterising Leaf based Low Adhesion on Railway Rails", Tribology International, Vol. 185, 108529.

Ref 5: University of Sheffield wheel on rail low speed testing

- Jaffé J, White B, Lanigan J, Mills R, Lewis R, 2023, "Assessing the Effects of Changing Conditions on Leaf Friction: Utilizing a Climate Chamber and Novel Full-Scale Rig Methodology", under review, Tribology International.

Ref 6: University of Sheffield High Pressure Torsion testing

- Evans M, Skipper WA, Buckley-Johnstone L, Meierhofer A, Six K, Lewis R, 2021, "The Development of a High Pressure Torsion Test Methodology for Simulating Wheel/Rail Contacts", Tribology International, Vol. 156, 106842;
- Skipper WA, Nadimi S, Watson M, Chalisey A, Lewis R, 2023, "Quantifying the Effect of Particle Characteristics on Wheel/Rail Adhesion & Damage through High Pressure Torsion Testing", Tribology International, Vol. 179, 108190.

Ref 7: University of Huddersfield full scale experiments developing highly adherent leaf layers

- Brant J, Stow J, 2023, "Final Report – Highley Adherent Leaf Layers", RSSB Ref: COF-UOH-72, IRR Ref: 110/246.

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 vegetation in areas that have been confirmed as potential leaf fall problem sites to sufficiently mitigate the risk, and to ensure that other areas do not become like them. A 'scorched earth' policy is impracticable, costly and environmentally unacceptable.

The following photographs taken at East Farleigh were taken before and after remedial action.

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), or are obstructing signals, destabilising structures, or those that pose a threat to safety if they fall.

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. Care must be taken to ensure that killing trees does not lead to unstable embankments, recognising that trees themselves can damage earthworks, e.g. roots disrupting culverts and drainage, and also drying banks out in the Summer.

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.

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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 (section A1.2.1).

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. Genuine meadow habitats are the most biodiverse habitats in the GB.

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 and chippings may be sold for biodigestion. Markets should be sought before clearance starts. 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 that do not produce leaf fall problems. There are various species available, including species that are native to the area being planted. 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.

Edition 7, May 2024

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 landowners can be approached to see whether they can assist in removing the problem.

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 provides 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;
- Less leaves / debris can get into drain catch-pits, therefore reducing flooding or earthwork erosion risks;
- There are fewer hiding places for lineside trespassers;
- It increases ability to identify defective fencing assets;

A rolling programme of routine work would allow regions to have specific in-house teams doing a small amount of work, rather than spending lump sums on contractors obliterating the vegetation every ten years or so.

A4 Troublesome trees

This section 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.

Tree professionals should be consulted where tree planting is proposed either on Network Rail land or on land adjacent to the railway. When selecting species, lower grown native shrub species are preferred; high leaf fall risk tree species should be avoided.

Sycamore

Horse Chestnut

Sweet Chestnut

Ash

Poplar

Lime

A5 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.	Removes source of leaf film contamination, but sustainability must be considered, c.f. the Varley Review.
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 for rails	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.

Edition 7, May 2024

	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	Enzymes being investigated (section A1.5.5).
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

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	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	Trials in Wales and Scotland mounted on a Road Rail Vehicle.	In Autumn 2022, Network Rail gave PlasmaTrack access to a Multi-Purpose Vehicle to trial on a Heritage Railway (section A1.5.2).
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.

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	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	-	Now being developed as Water-Trak (section A1.5.8).
25	Train mounted laser railhead cleaning	High power laser used to clear railhead of contamination. Mounted on dedicated vehicles.	Being used on metros in the US. Recently trialled on GB heritage railway (section A1.5.3).
26	Steam cleaning treatment train	None.	Little reduction in quantity of debris.
27	Adhesion modifier (sandite) train	Standard treatment including the use of stainless steel grit when track circuits are vulnerable. Needs	Good results. Adhesion increased by 5% on damp leaf film with a typical maximum value of 10%.

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	Method	Observations	Results
		repeating and limited to 40mph laying speed. Alternative product TractionGel 60 (TG60) allows for greater laying speeds.	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.
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	Trials conducted on Romford Upminster branch 1999. Some anecdotal success. Trial of GPS controlled raising and lowering of blocks on Merseyrail autumn 2001.

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	Method	Observations	Results
		developed and trialled. Considered that whole fleet would need fitting to be effective replacement for other measures. Cannot be used in conjunction with laying adhesion modifier.	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.
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).

	Method	Observations	Results
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.
39	Leaf fall prediction	Data supplied by weather forecasters, e.g. MetDesk, Met Office, MeteoGroup etc.	Reasonably accurate but predictions cover large areas.
40	Portable tribometers	Used to measure the adhesion levels on rails.	Originally testing by BR Research and Railtrack / Network Rail concluded OK for guidance and identifying trends. More recently a

Edition 7, May 2024

SCSG

	Method	Observations	Results
			portable tribometer from Rivelin Rail has been endorsed by the ARG (section 4.1.3).
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. LAWS is no longer in use, but there are a number of modern technologies performing similar functions (section 5.5.3).
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. Illuminated signs switched on only when low adhesion conditions likely or experienced (PADS™).	Effective in providing drivers with reminder of high-risk sites and reducing delays by advising only when conditions are poor. PADS™ no longer used.

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	Method	Observations	Results
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. Water / abrasive technology now being developed (section A1.5.4).
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.

	Method	Observations	Results
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 – Adhesion Management System (AMS)	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.	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. In its present form, the business case is only viable for short high intensity railways.
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.

	Method	Observations	Results
50	Service Train Adhesion Modifier (ATUST)	Railhead treatment equipment fitted to standard service train, laying either Sandite or TG60. Controlled automatically by train location equipment over pre-planned sites.	Experimented with by Network Rail and Greater Anglia railway during 2010-2012, operating out of the Smethwick and Cambridge depots. Concept moved to trialling on multiple units in service during autumn 2013-2014, reducing reliance on special treatment trains. Trials continued to around 2021 when increased lineside TGA installation made it less beneficial.
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	For tests on clean rail, Tergitol and Gum Arabic were observed to	As Gum Arabic fared similar to testing with water, Tergitol was

SCSG

	Method	Observations	Results
	friction properties at the railhead (COF-TAR-04)	slightly increase friction when measured on clean rail.	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). Follow-up work undertaken through 'Autumnsense' (COF-AUT-01 and COF-AUT-02)	Developed low cost (<£100) self-contained moisture sensors that successfully identified wet and dry periods under both laboratory and field conditions. Trialled on the Cross-City line (Birmingham).	Low-cost moisture sensing can be used to reliably to provide alerts on dew point formation and light rain. They can also detect the latent drying effect, common in damp, cool autumn conditions detecting more damp hours than those captured by standard meteorological observation sites.
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	The methods were found to be effective at completely cleaning laboratory and field generated leaf film from railhead while using lower volumes of water. Sloan Water Technology Ltd formed to enable commercial exploitation.

	Method	Observations	Results
		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.	
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 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.	Small and full-scale testing suggests braking performance could be improved. Now being demonstrated on the main line (section A1.5.1).
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	Funded by Innovate UK in 2016, TRL carried out measurements on one Class 159 wheelset, showing merit. Network Rail funded further field testing during 2022 at RIDC Tuxford using MPV on artificially simulated adhesion. Algorithms show promise.

	Method	Observations	Results
		braking, coasting or motoring (RSSB R&D project T614 and T959).	
57	Predictive Adhesion Management System (PAMS) software provides an 'alarm-based' prediction of when and where low adhesion incidents may occur on the GB mainline	Trialled Stratford to Shenfield, and the Piccadilly Line in autumn 2020. Utilised data from the Met Office (refreshed every 30 minutes), WSP data (from Class 345s) and 'static data' (topography and vegetation information).	Plans to incorporate more on-board train sensors to feed into PAMS did not proceed due COVID-19. No further trials are thought to have taken place since autumn 2020. Like AMS (#48), in its present form, the business case for the full PAMS system is only viable for short high intensity railways.

Edition 7, May 2024

A6 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-section titles added to aid 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.

Edition 7, May 2024

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.

Edition 7, May 2024

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.

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

Edition 7, May 2024

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.

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.

Edition 7, May 2024

A7 Autumn investigations

This appendix summarises industry investigations into low adhesion that identified the:

- Root causes;
- Extent of the problem;
- Effectiveness of the control measures.

The analyses were conducted between 1999 and 2016 and hence present an historical assessment. The results 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**. They have been kept in this manual to assist the industry in retaining these lessons and to avoid having to re-learn them.

The following investigations are summarised:

- Project NADIR 1999;
- Project NADIR 2003;
- Adhesion related incident database;
- Autumn 2005 investigation;
- Autumn measurement trials 2006;
- Review of Autumn 2010 by John Curley and David Rayner;
- Review of Autumn 2013 by John Curley and Claire Volding;
- Review of Merseyrail's Autumn 2013 by Plurel;
- European review to establish best practice 2016.

Edition 7, May 2024

A7.1 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.

- 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%).

A7.2 Project NADIR 2003

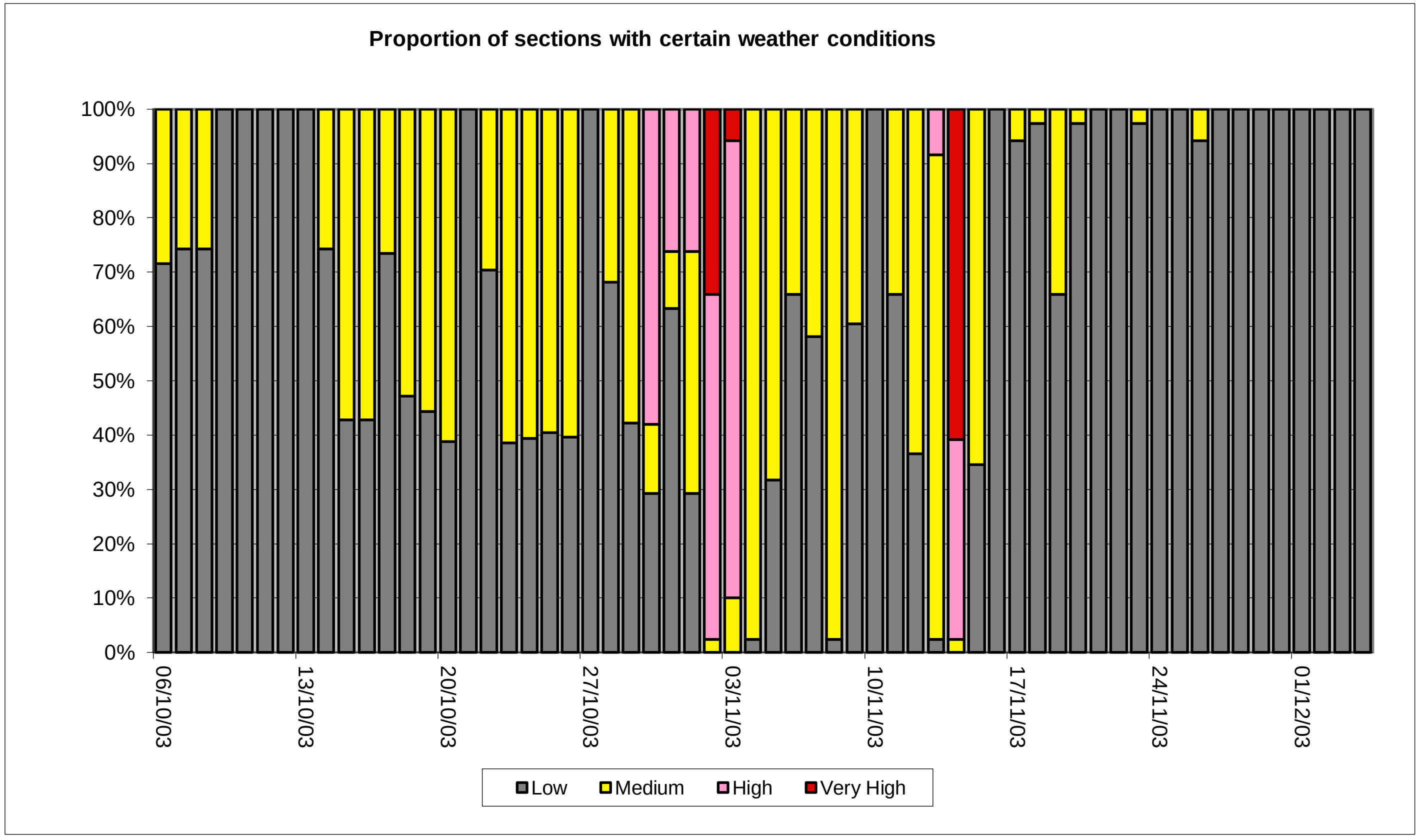
In 2003, Network Rail repeated the NADIR exercise to establish whether the same factors were still evident. Performance was studied on the original 18 routes, together with three additional routes. In addition, the network as a whole was studied, but the totality was to a slightly reduced analysis scope, 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?

Edition 7, May 2024

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).

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.

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.

Edition 7, May 2024

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 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:

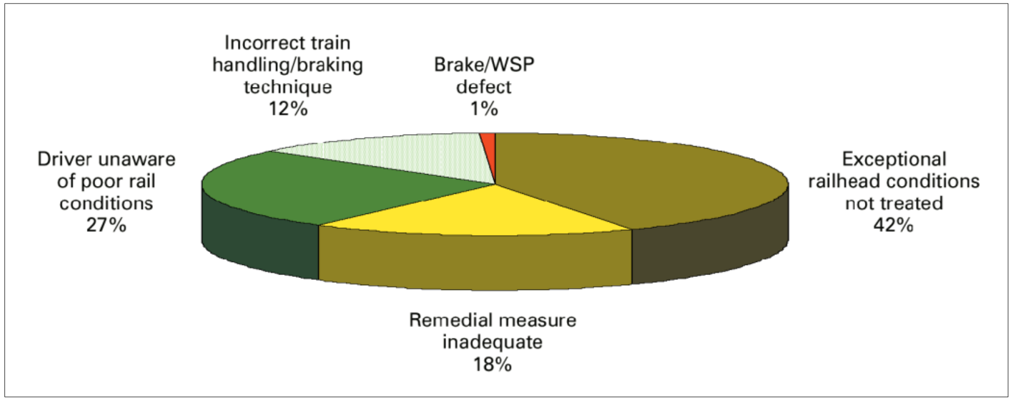
- Standardise and implement best practice defensive driving and communications measures.
- Fit sanders for braking and traction to all disc-braked stock used on services susceptible to adhesion delays.
- Design, cost, evaluate and implement a full vegetation management programme targeted at grade 5 locations 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.

Edition 7, May 2024

A7.3 Adhesion related incident database

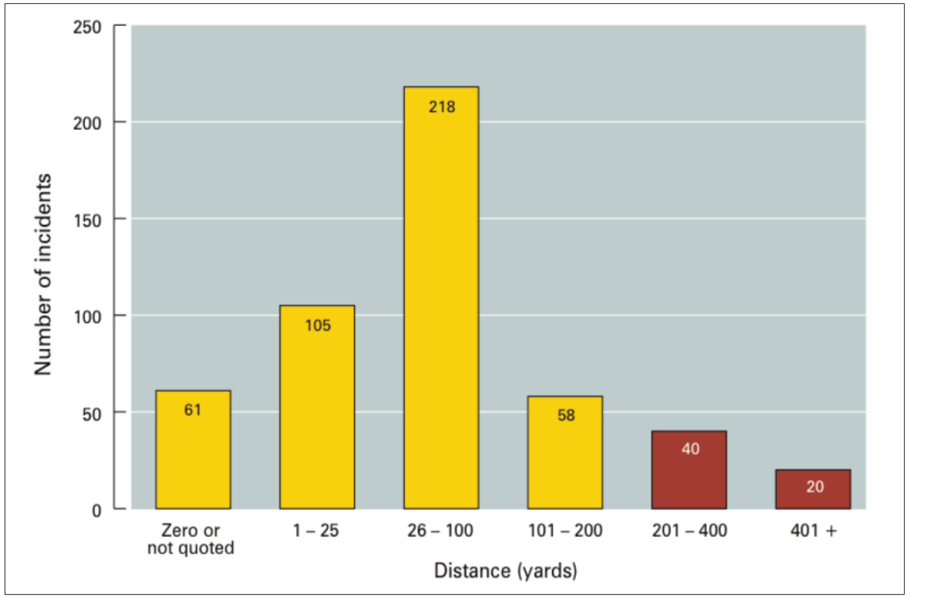
The following data is an analysis of the Adhesion Related Incident Questionnaires submitted by train operators to AWG between 1995 and 2000. Over 1000 datasets are included in this analysis. Although the data is now over 13 years old, it is still considered to be valid. The questionnaire concentrates 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.

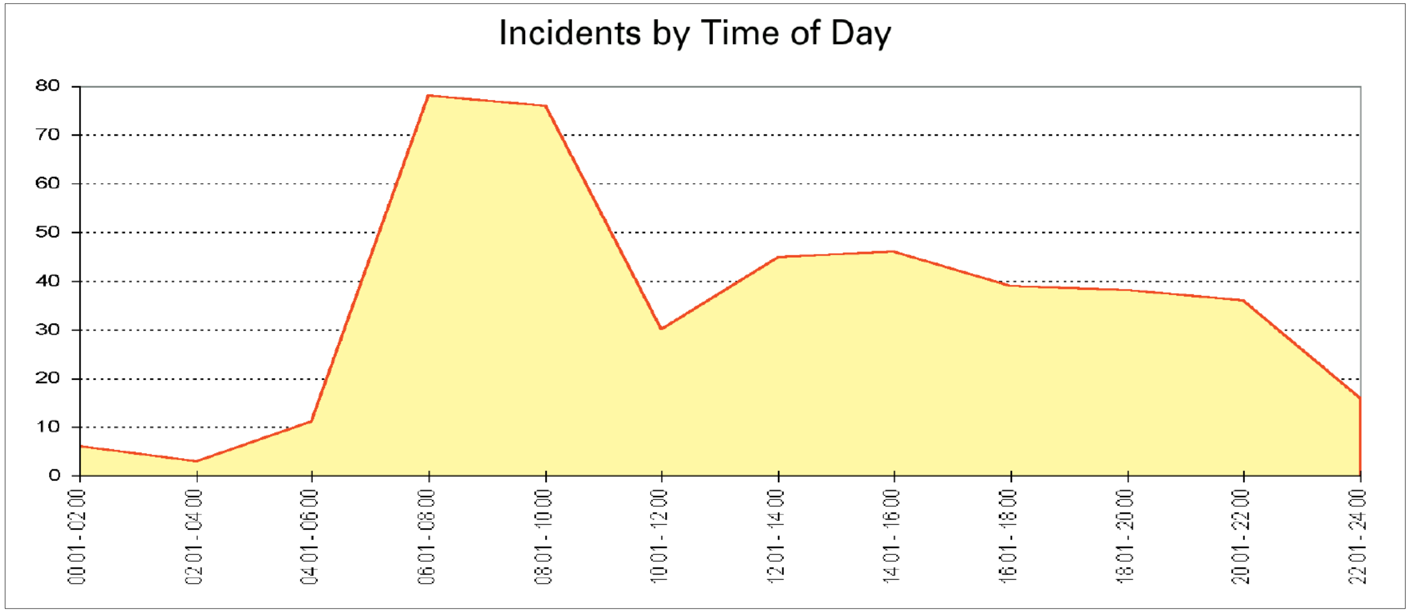
- Overrun distances – the chart below categorises the reported length of overrun.



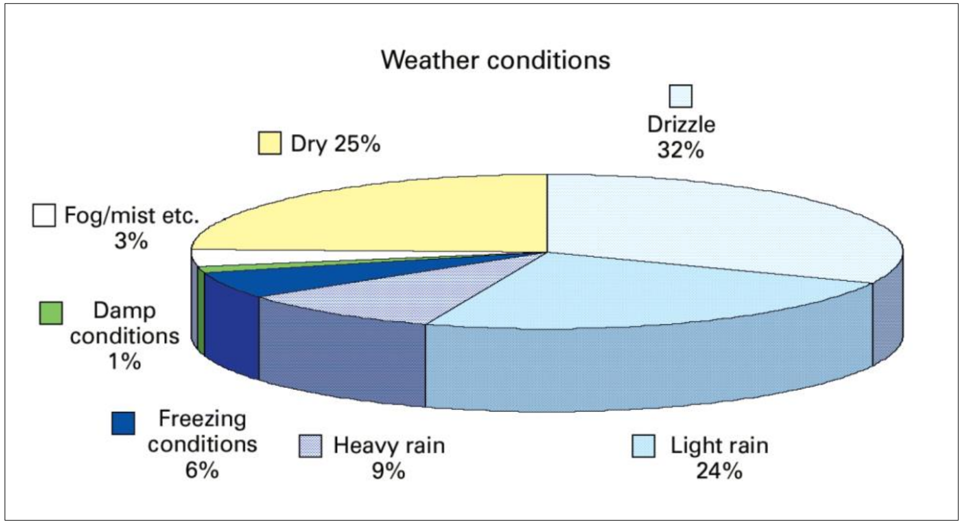
60 incidents (12%) were in excess of the 'normal' signal overlap distance of 200 yards. These 60 cases can be broken down as follows:

- 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.

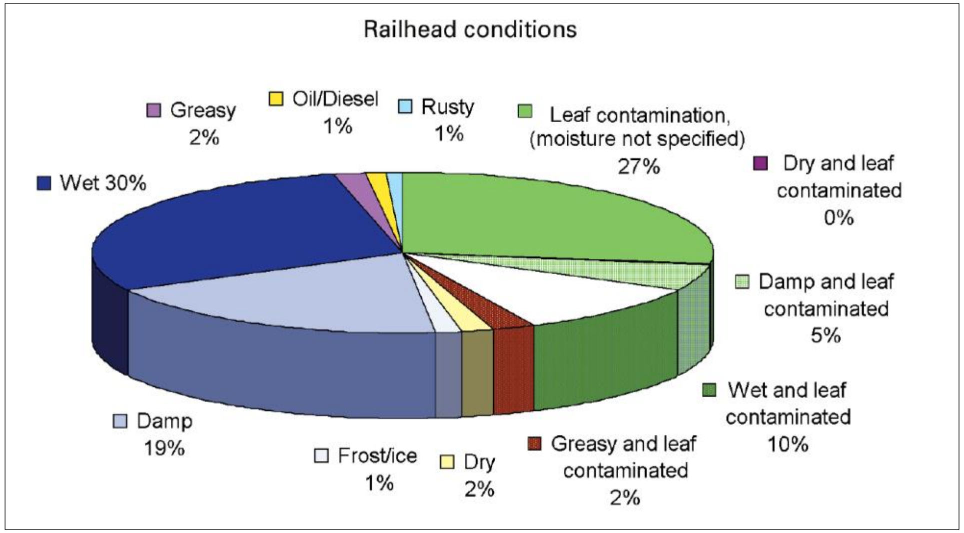
- Time of day – the graph below shows the incidents by time of day. It should be noted that the data has not been 'normalised' i.e. it does not take into account how many trains are usually in service at the various times of the day. The incidents are predominantly in the morning peak, but this is as 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.



- 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%).**

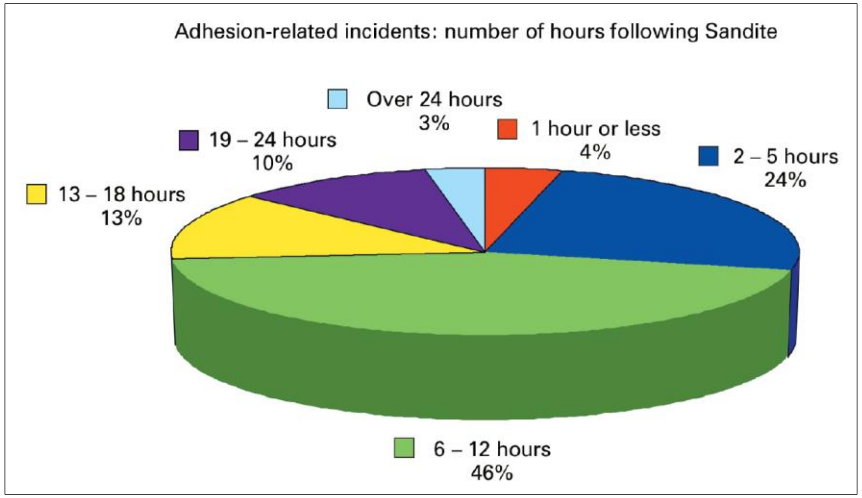


Edition 7, May 2024

- 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.

Edition 7, May 2024

- 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.

A7.4 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.

Edition 7, May 2024

- 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.

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.

Edition 7, May 2024

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.

A7.5 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

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.**

A7.6 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.

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.

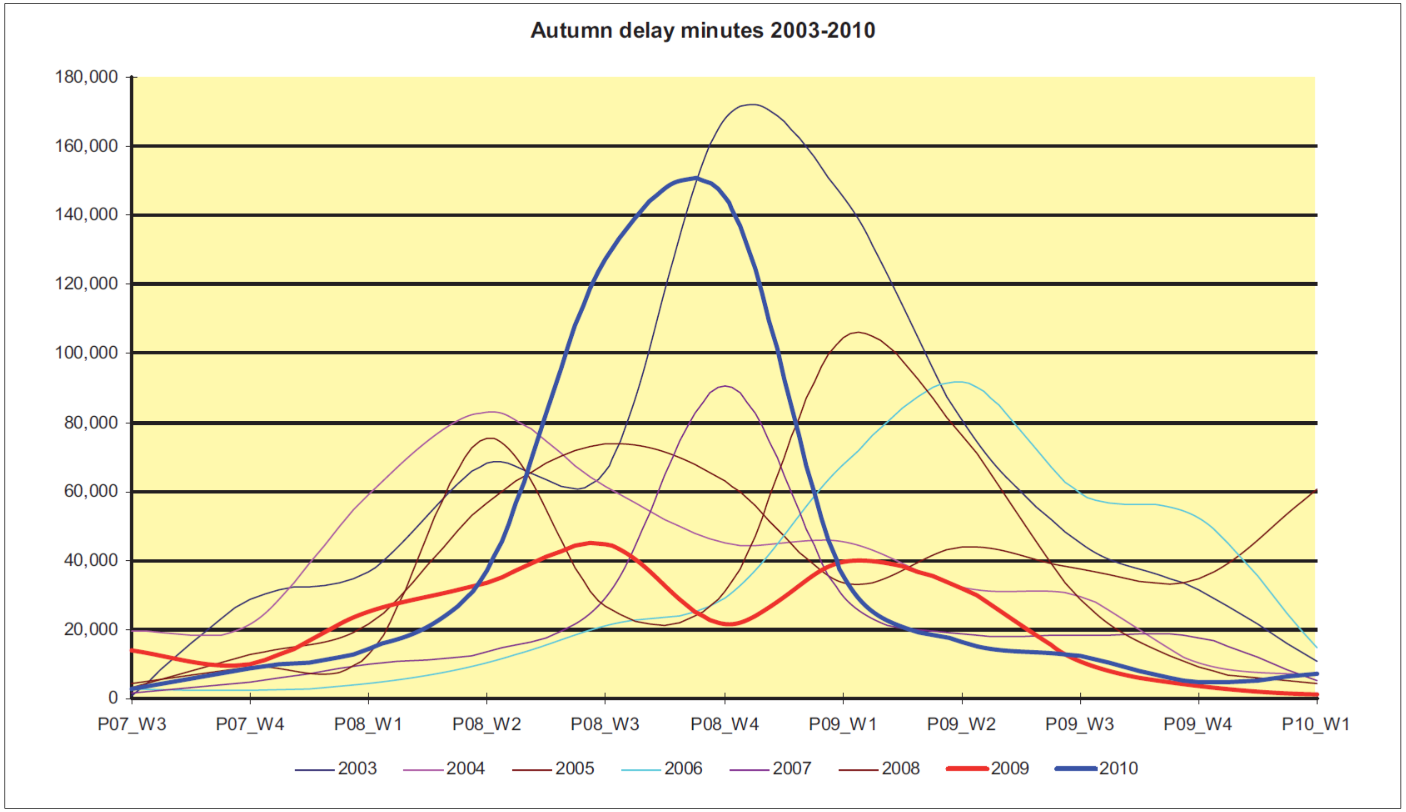
The data confirmed the picture of increasing numbers of WSTCF over recent years to 2010. Until recently WSTCF were only known about if they were either observed by the signaller or resulted in the interlocking registering their occurrence. In many cases WSTCF are transient and can potentially go unobserved. 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.

Edition 7, May 2024

SCSG

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.

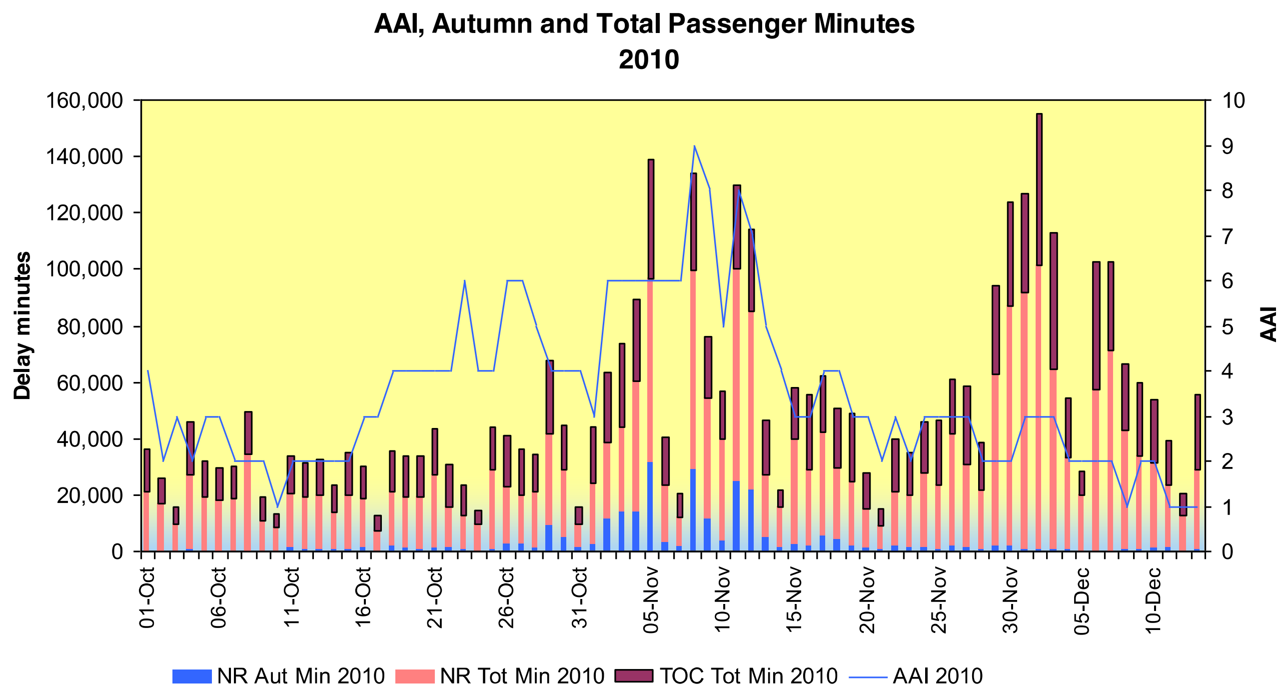


Edition 7, May 2024

Managing Low Adhesion

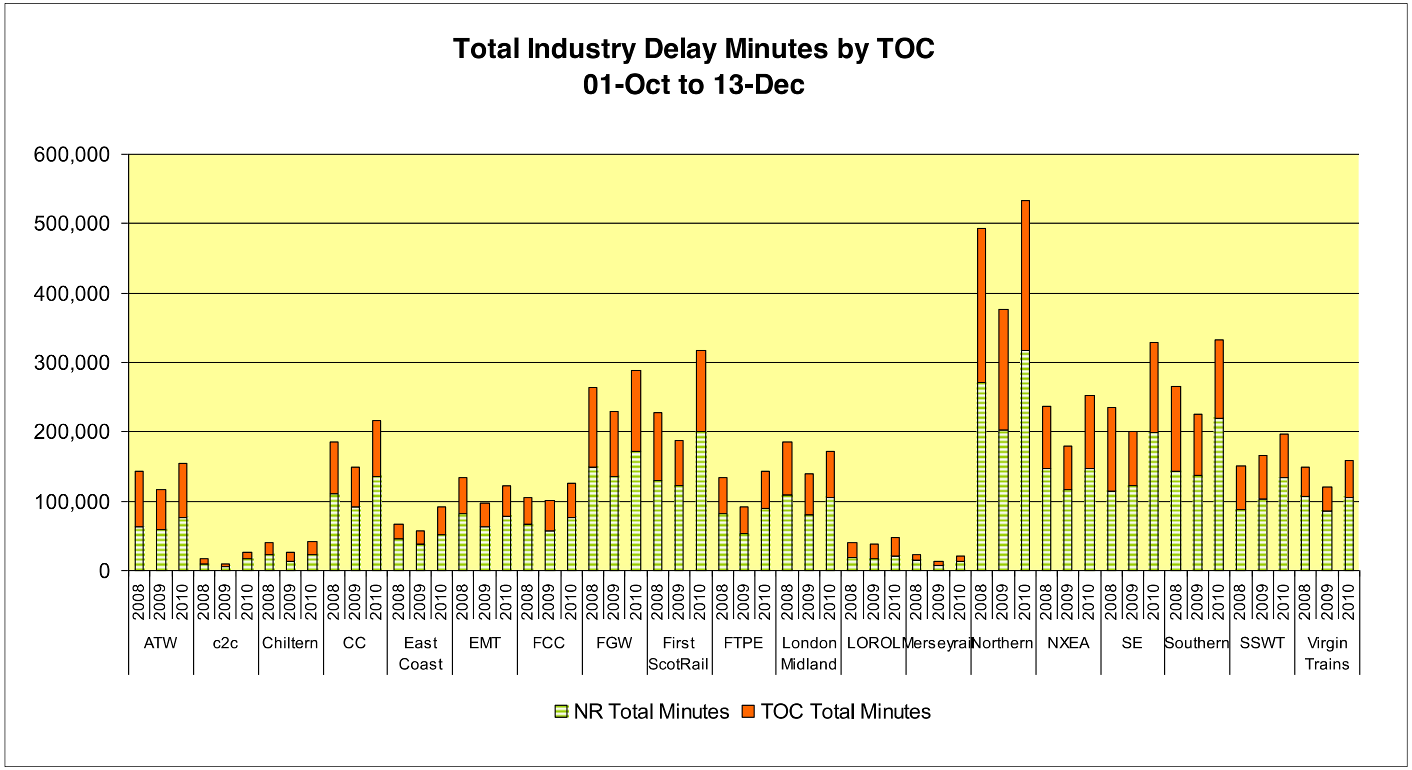
SCSG

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

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.

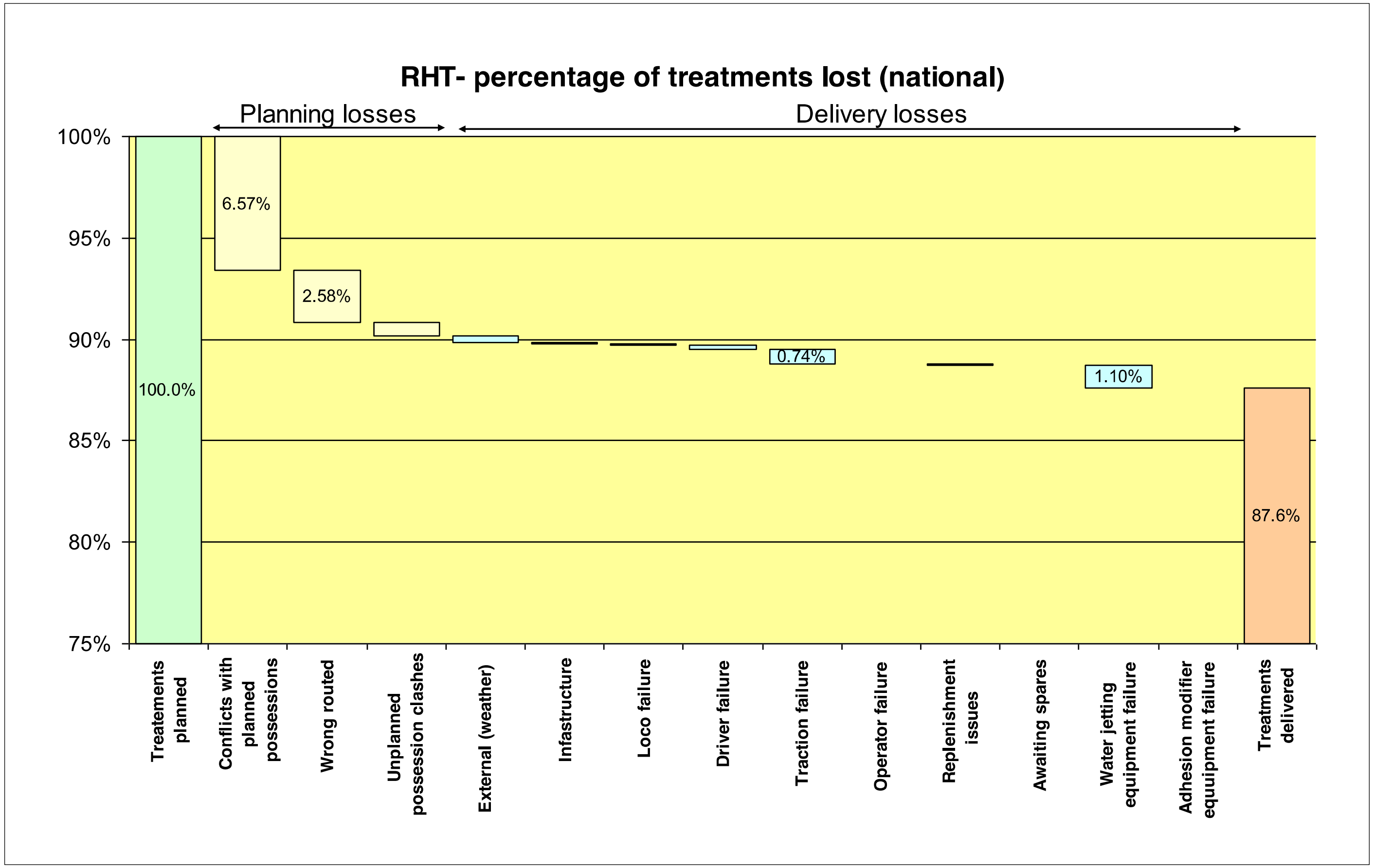
Railhead Treatment Programme

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.**

Managing Low Adhesion



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.

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.

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 – GERT8000-TW1 “Preparation and movement of trains”.

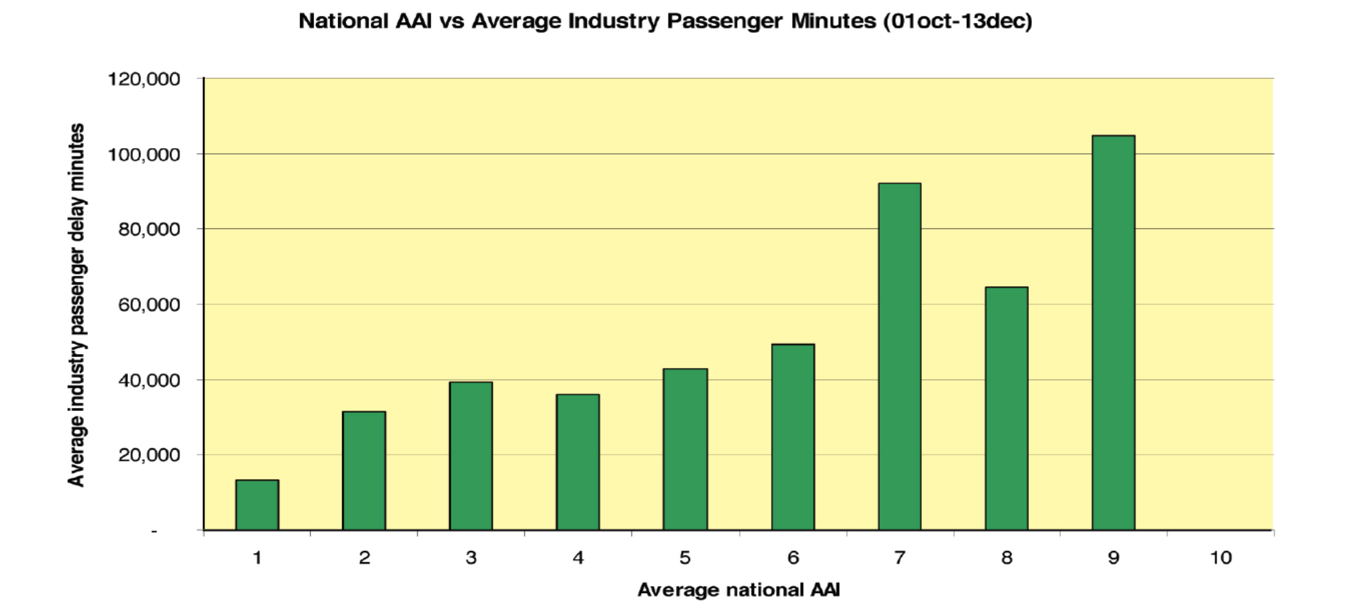
Whilst the quality and geographic detail of the autumn forecasts is recognised to have improved markedly it is not sufficiently focused to predict the specific conditions that a driver will meet over the course of their shift. The emerging data from the detailed measurement of microclimate carried out during autumn 2010 on Wessex Route, in

Edition 7, May 2024

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.



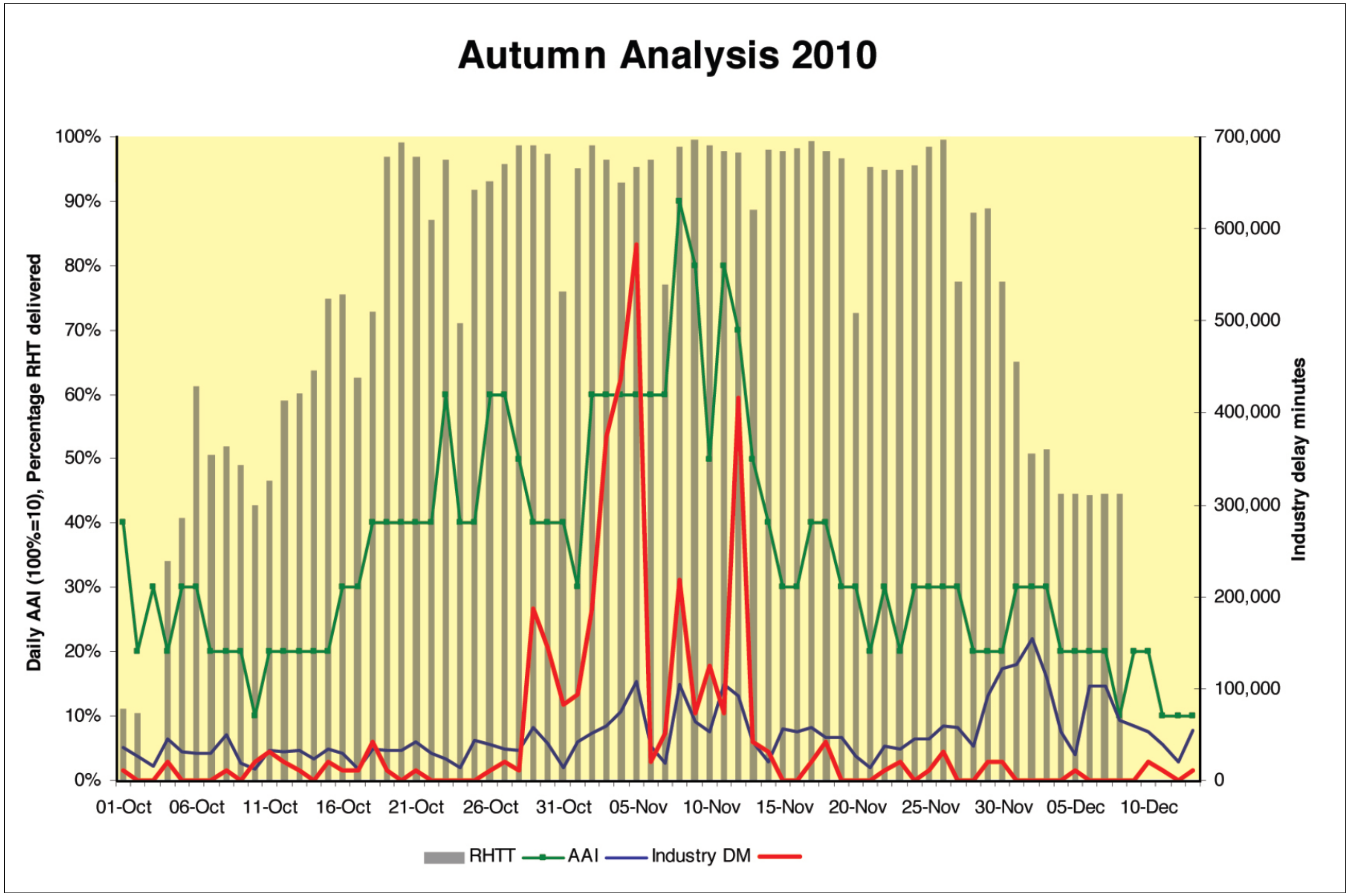
Note: The apparent inconsistency in the data above for a National AAI of 8 is a statistical anomaly due to a very small dataset

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.

Edition 7, May 2024



A7.7 Review of Autumn 2013 by John Curley and Claire Volding

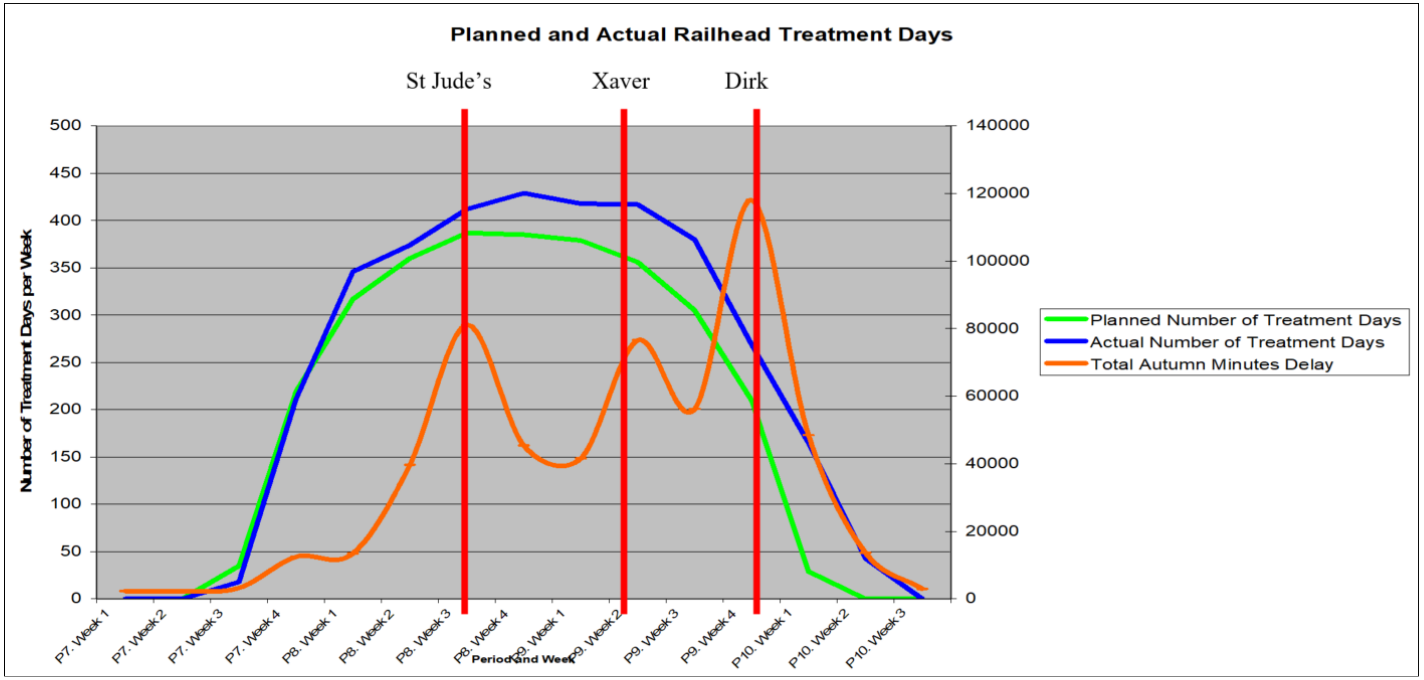
In November 2014, National Task Force (NTF) agreed that an independent review should be commissioned to address the materially higher autumn safety KPIs and delay minutes of 2013. The review used semi-structured interviews with key individuals and teams across the Industry.

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.

Managing Low Adhesion

- 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.

- 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.

Edition 7, May 2024

A7.8 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.

Edition 7, May 2024

A7.9 European review to establish best practice 2016

In 2016, RSSB conducted a knowledge search "European Fact Finding on Adhesion" (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.**

Edition 7, May 2024

A8 Key recommendations

The following lists the recommendations made throughout this manual, that have been **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	4.3.1	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	5.2.2	Units operating in multiple can, and should have all of their sanders active.
4	5.3.1	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.
5	6.1.3	Train Operated Warning Systems (TOWS) must be taken out of use.
6	A1.2.5	Railhead treatment should be used to improve traction where acceleration problems occur particularly on gradients or on the exit of stations.
7	A1.2.5	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.
8	A1.2.11	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.

Edition 7, May 2024

SCSG

	Section	Recommendation
9	A1.3.2	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	A7.5	Wheel contamination should be considered as a significant factor in the braking performance of trains.
11	A7.5	Water jetting and adhesion modifier treatment (such as sandite) provides the best method for improving adhesion in autumn conditions and should be used where possible.
12	A7.6	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.
13	A7.6	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.
14	A7.6	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.
15	A7.7	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:

Edition 7, May 2024

SCSG

	Section	Recommendation
		▶ 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.
16	A7.9	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;

	Section	Recommendation
		▶ 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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Rail Delivery Group

National Rail