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Development of a Model to Assess the Risk of Low Adhesion at Different Rail Sites

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Abstract

A new low adhesion risk model has been developed which can be used to help better identify high-risk sites and tailor a risk-mitigation plan accordingly. A case study of the Chiltern Railways Company Limited network focusing on WSP activation data and vegetation surveys was carried out. To construct the model, locations on the network were analysed and scored for specifically chosen parameters relating to low adhesion (including tree factors, track information etc.). The outcomes were validated against the frequency of WSP activation. The resulting model is capable of predicting the level of risk for any precise GPS location, with the intention of enabling infrastructure managers and operators to plan enhanced rail cleaning strategies, vegetation management schemes or equivalent. Ultimately, this should improve Autumnal delay performance and ensure passenger safety is maintained throughout the year.

Keywords: adhesion, leaf layer, model, autumn, prediction.

1 Introduction

Low adhesion at the wheel-rail interface causes traction problems (especially when accelerating or braking), significantly affecting autumn network performance. The estimated annual cost of low adhesion to the UK rail industry exceeds £350 million [1].

Low adhesion delays occur when leaves are crushed in the wheel-rail interface and "black leaf layers" are formed. This layer is known to reduce friction coefficients (μ) to below the critical value μ=0.1, constituting major safety risks for accelerating/decelerating trains. Reduced braking effectiveness can cause Signals Passed At Danger (SPADs), station overruns and collisions. Examples of these are described in Rail Accident Investigation Branch (RAIB) reports [2,3].

Figure 1: Bonded black leaf layer

The problematic leaf layer shown in Figure 1 adheres strongly to the railhead, significantly reducing adhesion at the wheel-rail interface [4]. Current railhead treatment methods include depositing sand or traction gel and water jetting.

In order to help the rail industry, manage the issues caused by low adhesion and leaf layers in particular, by changing timetables; keeping drivers informed and planning more effective mitigation, several companies provide low adhesion prediction services, similar to weather forecasts. Current adhesion prediction models do not consider specific physical site features and tree species present. The model being developed does take these into account and should be able to provide those involved with track and vegetation management with more detailed information on where and why there may be a higher risk of low adhesion occurring.

This paper describes the development of a model to predict low adhesion risks at given locations. It was based around a case study site but can be rolled out to other locations easily. The model utilises inputs from field surveys and laboratory testing (including a detailed analysis of leaf chemistry) to create a comprehensive low adhesion forecast. It is intended to be open source, with a simple, modular design allowing users to adjust for their specific needs. Model outputs will be communicated in a way that is easy for users to access and understand (i.e. heat maps), allowing them to inform decisions on railhead cleaning approaches and vegetation management.

The Chiltern Railways Company Limited (CRCL) network (see Figure 2) was selected for the case study used in the model development.

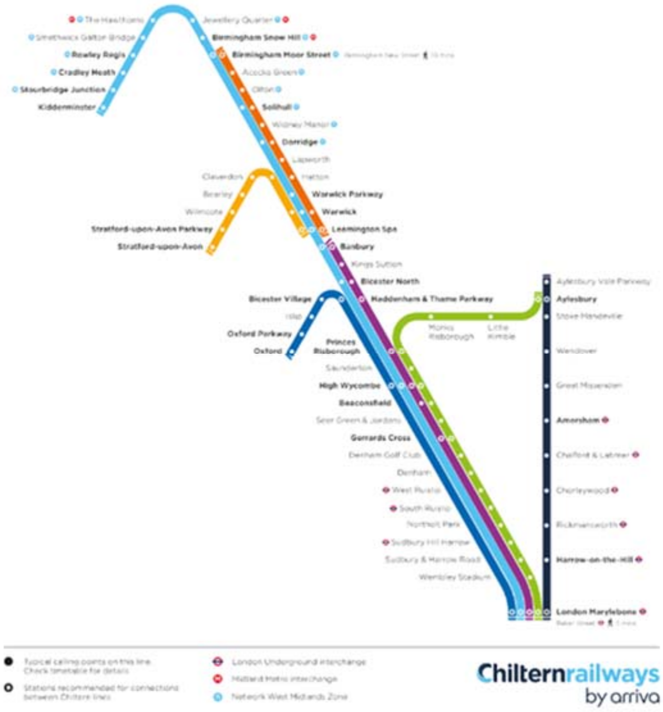

Figure 2: CRCL Network [5]

CRCL Wheel Slide Protection (WSP) raw data was used to tune the model. Data from 'COMPASS' incident management software and On Train Data Recorders (OTDRs).

2 Methods

Specification

For optimal usage, application and potential modifications of the model, it was decided that it should:

- allow users to update location information, keeping input data easily accessible.
- ensure railhead contamination risk is easily determined using basic site observations (e.g. proximity of vegetation) and measurement tools (e.g. tape measure, camera).
- have an open, modular design that can be adapted/incorporated into larger autumn performance tools.
- allow users to input new WSP data to update the model.

The model assesses risk using 10 parameters (fixed and temporal), with a specific scoring mechanism. Fixed parameters include:

- Local terrain - track gradient, whether the track is in a valley/flat/raised
- Signal diagram information - speed limits, number of services etc.

Parameters that may change over time (temporal) and should be updated, include:

- Distance of treeline from rail
- Linear spread/density of treeline etc.

Each parameter is expected to contribute to the risk of leaf layer formation and WSP activation.

Development

Model development involved the following stages:

a. Analysis of WSP data

109 instances of WSP activation covering ≈ 3 years were analysed, focusing mainly on the location. This was used to assess low adhesion risks for key locations on the case study route, aiding model development and validation. Date and time of the slips was also analysed and could be used as supplementary information by model users, or in the future to make the model time based.

b. Location organisation

Locations shown in Figure 3 were grouped using the method shown in Table 1.

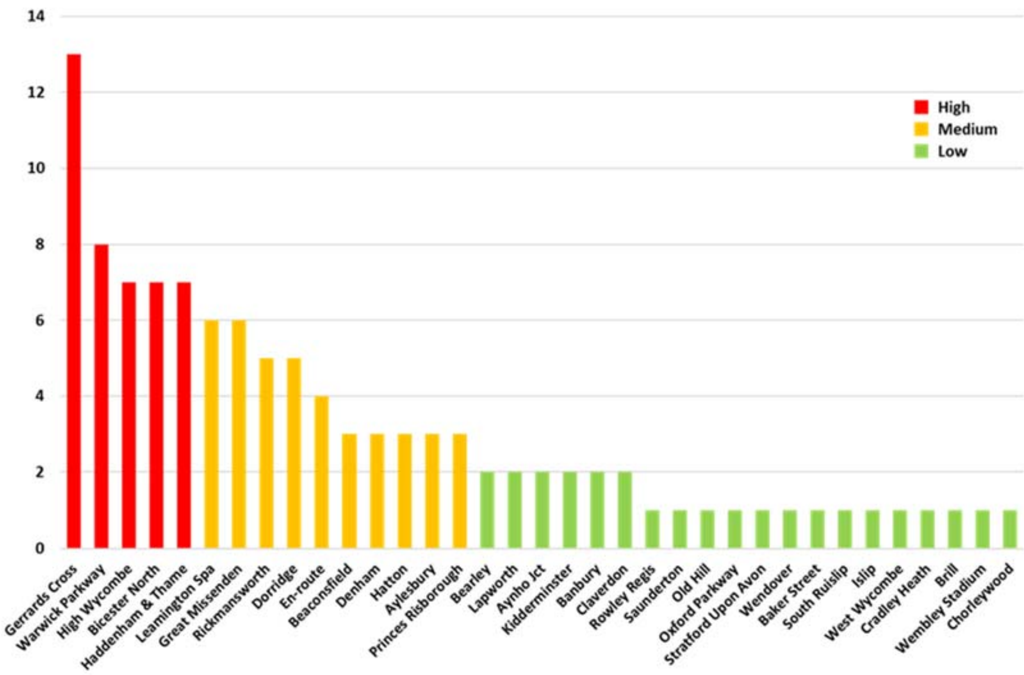

Figure 3: Frequency per location

Grouping	**High**	**Medium**	**Low**
Frequency	$x \geq 7$	$6 \geq x \leq 3$	$x \leq 2$
Score	3	2	1
Colouring	Red	Amber	Green

Table 1: Location scoring mechanism

Locations were split into two groups, with close to equal representation from each category. The frequency score was known for Group 1, which was used to identify parameter trends for weighting. Group 2 was used to validate the scoring and parameter weighting; the frequency score was hidden to reduce unconscious bias.

c. Model set-up

Microsoft Excel was used for the model development as it is widely accepted in industry. Parameters and scoring criteria were listed on the left, locations on the right, total scores per location are shown at the bottom (see Figures 5, 6 and 7). The vegetation distance parameters were partially informed by vegetation standards outlined in the Varley report [6].

3 Results

d. Signal diagram analysis

Signal diagrams provided crucial model inputs on gradient, speed limit, number of lines at a location.

e. Site investigation

Through vegetation surveys, physical features were measured, i.e. proximity of vegetation to rail, species present etc. Where site visits were not possible, Google Maps and Street View were used to measure the distance of the treeline from the rail and other parameters.

Figure 4: Google Maps screenshot of Gerrards Cross [7]

Figure 4 shows Gerrards Cross station with a measurement of the depth of the treeline.

f. Weighting adjustments

Once the initial half of locations (Figure 6) were benchmarked with incident frequency data, the parameters (Figure 5) were then mathematically analysed and ranked based on how well they fitted the frequency data.

g. Model validation and refinement

The aim of the refinement was to adjust the total score thresholds (bottom of Figure 5), so the total score was either the same, or higher, than the delay frequency (top row). The overall location score thresholds were also changed to give the best fit to the frequency data.

Following this, Group 2 (see Figure 7) were fed into the model 'blind' (frequency delay scores were initially removed) so that research bias was removed as much as possible.

h. Model overview

The inputs to the low adhesion risk model are contained within Microsoft Excel, see Figures 5, 6 and 7.

Parameter		Range				
		3	2	1	0	
Delay frequency						
Tree coverage	Tree species	-	-	Problematic species present	Problematic species not present	4
	Overhanging the line (overhanging/not overhanging)	-	-	overhanging	not overhanging	2
	Linear spread (or density) along the line (packed or spread)	high	medium	low	no trees	10
	Distance from track in m	less than 3m	between 3m and 5m	between 5m and 10m	over 10m	5
	Depth of trees (away fom track)	over 10m	between 3m and 10m	less than 3m or single tree depth	no trees	8
Local terrain	Embankment/flat/cutting-shallow sides/cutting-steep sides	steep, high cutting	medium cutting	flat, no cutting	track is raised	9
Key track features	Gradient	1/265 or steeper	between 1/265 and 1/429	less steep than 1/429	flat	7
	Train speed limits	100 or greater	99 - 75	74 - 60	59 or less	3
Service	No. of lines running through station	4	3	2	1	1
Local area	Rural or urban	-	-	Rural	Urban	6
Total						

(green)	<=	49
(yellow)	between	50
		101
(red)	>=	102

Figure 5: Scoring mechanism and parameters of the model

Figure 5 shows the parameters and scoring criteria of the model, with the ranked weighting factors on the right-hand side. Seven of the parameters are scored between 0 and 3 (where 3 represents a higher risk and 0 a lower/no risk). The remaining three parameters are scored 1 or 0, due to the nature of the parameters. Thresholds for total scores are shown at the bottom of Figure 5

Case Study Sites																	
1 - Gerrards Cross	2 - High Wycombe	3 - Beaconsfield	4 - Great Missenden	5 - Princes Risborough	6 - Claverdon	7 - Leamington Spa	8 - Bearley	9 - Hatton	10 - Old Hill	11 - Chorleywood	12 - Lapworth	13 - Wembley Stadium	14 - Rowley Regis	15 - Wendover	16 - Islip	17 - Kidderminster	18 - Oxford Parkway
3	3	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	0	1	1	1	0	1	1	0	0	1	0	1	0	0
3	3	2	3	1	1	1	1	1	2	2	2	2	2	1	1	2	1
3	3	3	3	2	3	2	3	2	3	3	2	2	3	3	3	2	2
3	1	2	1	1	1	1	1	2	2	2	3	2	1	1	2	1	1
3	3	3	2	1	1	1	1	1	2	1	2	2	1	1	1	2	1
3	1	3	1	3	0	3	0	0	3	3	1	3	3	3	0	0	0
3	2	3	2	2	3	2	1	2	0	1	3	3	0	2	3	0	0
3	3	3	0	3	0	2	0	2	1	0	1	3	0	0	0	0	0
0	0	0	1	1	1	0	1	1	0	1	1	0	0	1	1	1	1
135	102	117	96	77	63	72	57	63	97	96	99	101	79	79	71	66	47

Figure 6: Group 1

Figure 6 shows Group 1 with colour coded scores. The total scores for each location are shown at the bottom and are made up of the sum of the scores for each parameter, multiplied by the weighting factor.

Cross Check Sites														
West Wycombe	Cradley Heath	Stratford Upon Avon	Brill	Aylesbury	Bicester North	Rickmansworth	Saunderton	South Ruslip	Haddenham & Thame	Warwick Parkway	Banbury	Denham	Dorridge	Aynho Jct
1	1	1	1	2	3	2	1	1	3	3	2	2	2	2
1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
1	0	1	0	1	0	0	1	0	1	1	1	1	1	1
2	0	2	2	1	3	1	1	1	3	2	2	3	1	1
3	2	3	2	3	3	2	2	3	3	3	3	3	3	3
1	1	2	1	1	2	1	1	1	2	1	1	3	1	1
1	1	2	1	1	1	1	1	1	2	1	1	1	1	1
1	3	0	3	0	3	3	3	0	0	3	2	3	2	2
1	1	0	3	0	3	0	3	3	3	0	3	3	1	2
1	1	2	1	2	1	1	1	3	2	1	2	2	3	3
1	1	0	1	0	0	0	1	0	1	1	0	1	0	1
75	62	77	84	50	105	63	80	58	102	86	83	122	68	77

Figure 7: Group 2

Figure 7 shows Group 2 (validation), where for all but one location (Warwick Parkway, due to unknown factors), the score at the bottom was the same or greater than the frequency delay score. The bias towards overestimating the risk was chosen deliberately as a safety measure.

4 Conclusions and Contributions

A comprehensive low adhesion risk prediction model, validated with wheel slide delay data from the CRCL network, has been compiled with the aim of improving low adhesion performance, especially during autumn months.

The model can now be used by CRCL and Network Rail (NwR) to focus remediation techniques at any given location within the model's scope. The model can also be used on other routes; this would require some additional field/observational work to feed into the model for a new route.

Figures 5 and 8 both display the ranked parameters that were found as an outcome of the mathematical analysis of the Group 1 data, where 10 was the most impactful and 1 was the least.

Parameter	Rank
Linear spread (or density of trees) along the line (packed or spread)	10
Embankment/flat/cutting-shallow sides/cutting-steep sides	9
Depth of trees (away from track)	8
Gradient of track	7
Rural or urban	6
Distance from track of treeline	5
Tree species	4
Train speed limits	3
Overhanging the line (overhanging/not overhanging)	2
No. of lines running through station	1

Figure 8: Ranked parameters

Figure 8 shows how the model fits the Group 2 locations, where all but one location gives the same (or higher) risk ranking when compared to the delay frequency. Warwick Parkway is an anomaly with a delay frequency score of 3-high but a risk score of 86, which is in the medium category.

Assumptions

Necessary assumptions and limitations were applied, these were out of the author's control in some instances (e.g. historical data). A more detailed list of assumptions will be listed in lead-author Thomas Butcher's PhD thesis.

For example, WSP events were assumed to have happened at the stations listed but could have occurred outside of the station limits. Not all wheel slip incidents will have resulted from low adhesion. Efforts were made to remove those not directly attributable to leaf fall, however, some could have been missed.

It is noted that vegetation surveys were carried out in October 2021 partly due to COVID-19 restrictions preventing a survey being carried out sooner, therefore, vegetation levels are likely different to those at the time of each WSP instance.

Planned Model Development

- Development of model software (i.e. generation of heatmap) and design of user interface (including how to easily edit the model)
- Roll-out across a second trial Train Operating Company (TOC) network, with possible nationwide implementation after a successful trial
- Additional input data from existing low adhesion forecasting models (e.g. NwR)
- Automatic updates to incident data from TOC recorded WSP activations (e.g. integration with Porterbrook Class 377 remote OTDR)
- Updated vegetation surveys (obtainable from NwR)

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