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A Study into the Effect of the Presence of Moisture at the Wheel/Rail Interface during Dew and Damp Conditions

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Abstract

Incidents involving low levels of adhesion between the wheel and rail are a recurrent issue in the rail industry. The problem has been mitigated using friction modifiers and traction enhancers, but a significant number of incidents still occur throughout the year. The following work looks at the environmental conditions that surround periods of low adhesion in order to provide an insight into why low adhesion events occur. Network Rail Autumn data, which provided details on the time and location of low adhesion incidents, was compared against weather data on a national and then local scale. Low adhesion incidents have often been attributed to contamination on the rail, such as organic leaf matter, but other incidents occur when no contamination is visible. The time, date and location of incidents were linked to local weather data to establish any specific weather conditions that could lead to these events. The effects of precipitation, temperature and humidity on the rail were analysed in order to further the understanding of low adhesion in the wheel-rail contact, which will lead to better methods of mitigating this problem.

Keywords

Wheel/Rail Interaction, Tribology, Railways, Low Adhesion, Dew

1. Introduction

Low adhesion in the wheel-rail contact presents a number of problems for the rail industry. Most obvious are safety concerns, the inability to brake effectively under certain conditions results in longer stopping distances. Additionally, low adhesion can result in wheel skid or slip which can cause damage to both the wheel and rail.

The wheel-rail contact is an open system and therefore exposed to a number of conditions and contaminants that may influence adhesion. Some of the causes of low adhesion in the wheel-rail contact are well understood. The issue of leaf contamination has been extensively researched [12], which has led to a number of mitigation methods being produced. However a recent RSSB project has highlighted that other low adhesion incidents will occur without heavy precipitation or visible rail contamination, organic or otherwise [3]. This has been named the "Wet-Rail" phenomenon, defined as "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. These conditions are not associated with continuous rain" [3]. Researchers have shown the impacts of temperature; humidity and natural contaminants on the tribology at the wheel-rail contact both in field tests as well as in laboratory studies [1,2,4].

The aim of this work was to improve the understanding of the weather conditions that lead to low adhesion, therefore highlighting the possible causes so that the problem can be mitigated more effectively. The initial stage of this work is to explore the link between low adhesion events and UK national average weather data, looking for any trends in the data. A previous report has been carried out on this subject that will be analysed and built upon [3]. The work was expanded by gathering data from local weather stations that are situated close to low adhesion events, in order to pinpoint the weather conditions at the time of incident. A flow chart that explains the structure of this work is shown in Figure 1.

2. Data Collection

The data used in the course of this study came from a variety of sources. The analysis was based on data provided by Network Rail, a list of incidents that have been attributed to low adhesion events during the autumn periods of 2010-2014, from the 1st September to 10th December. The data consisted of station overruns, signals passed at danger (SPADs) and wrong side track circuit failures (WSTCFs) attributed to leaf fall. The data includes the time, date and coordinates of incident. Extra notes were sometimes included that were taken during rail inspection after incidents, such as the presence of any visible contaminant or whether the rail head was in wet or dry condition. Data was not collected by Network Rail throughout the rest of the year so only autumn could be investigated.

This work focusses on linking this data, such as station overruns, to weather data obtained from SMT weather, a website which provides specialist meteorological data for Network Rail [5]. Weather data was available from a large number of weather stations across the UK and contained hourly measurements for the amount of precipitation, air temperature and wind speed. Humidity data was sampled from the MET office. A MET office report[6] has previously analysed 22 specific SPAD events using meteorological and leaf fall data.. The report concluded that slightly damp rails seem to cause more SPAD's then rails saturated with water and that many incidents occur when the relative humidity is high. This analysis will use low adhesion incidents that have been attributed by Network Rail to weather conditions and not leaf fall. Only station overruns have been examined, occurring more often than the other previously mentioned types of incident. The larger number of incidents enables better data analysis.

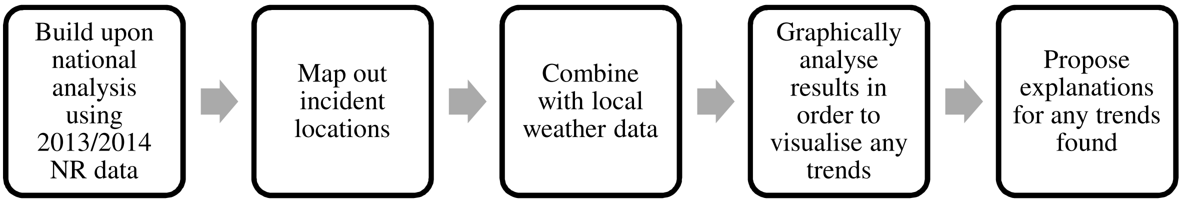

Figure 1. A flow chart explaining the structure of the current work

3. National Analysis Approach

As explained above, national analysis of Network Rail incident data during the autumn period was performed in the previous report [3] and some interesting trends were found. For example, in the 2010-2012 data sets it was reported whether leaf contamination was present or not after inspection following an incident. The reported numbers of incidents from both categories are shown in Table 1. It can be noted that the numbers of contaminated and non-contaminated incidents are roughly similar for all years. Data from the years 2013 and 2014 has not been included due to changes in incident recording.

Data set	**Leaf contamination reported**	**No leaf contamination reported**
2010	85	82
2011	20	27
2012	80	67
Total	185	176

Table 1. Rail contamination reported after an incident (taken from the NR autumn incident data)

The following reasons have been proposed as to why a large number of incidents have been reported as non-contaminated:

- There was no leaf contamination in the contact and the overrun was caused by another factor (not necessarily low adhesion).
- Leaf contamination was not present on the rail head, but was present on the wheels of the train.
- The rail head condition was assessed at a position where leaf contamination was not present, but was present elsewhere in the stopping zone.
- Leaf contamination was present at the point of assessment, but was not detectable by the assessor's methods (most commonly visual inspection).
- Water or moisture was present on the rail head and perhaps in combination with other third body contaminants, caused low adhesion.

It is unlikely that the overruns are caused by human factors or mechanical issues because Network Rail analyses driver records for each incident in order to asses if anyone is at fault and have determined the incidents used here as "weather related". It is unlikely that leaf contamination would purely be found on the wheels, few leaves would settle on them and contamination would quickly be removed due to the rotation and if it was the low adhesion is likely to be much more short lived because the high forces acting upon the same area of the wheel during slide would remove contamination. Proposals 3 and 4 are perhaps more likely due to the visual inspection method, although the hard black layer typically associated with leaf contamination is usually visibly obvious and notoriously difficult to remove, so the chances of it not being seen during inspection still seem unlikely. This paper will consider the final proposal and look at other methods of low adhesion that do not involve leaf contamination. The Network Rail 2011 Autumn Incident Report suggests that during visibly poor conditions, drivers anticipate low adhesion and make adjustments to their brake timing. If these seemingly uncontaminated low adhesion events are caused by low levels of water, the drivers may be unaware of these poor conditions and will not adjust their driving style.

It has been previously proposed that adhesion between the wheel-rail contact is lowest when the track is drying out [7]. If this is the case, multiple station stops may be successfully performed with dew present on the track. As the dew dries it may reach a critical moisture level, lowering the friction coefficient sufficiently for the train to experience low adhesion. If this was to occur, any moisture present on the rail head may have dried by the time the track is inspected and dry conditions reported.

The current work began with updating the previous work with 2013 and 2014 data, ensuring that there were no significant anomalies in more recent incidents compared to previous years. The only type of low adhesion event used in the following figures are station overruns that have been attributed to weather conditions by Network Rail, ensuring that the weather conditions are causing these issues rather than leaf fall.

Another major finding of the previous report was the bias towards weather related station overruns taking place in the morning and evening. It can be seen from Figure 2 that there is a substantial rise in station overruns during the hours of 0600-0900 and a smaller rise in 2000-2200. It is during these times that dew may be present on the rail head. Data has been normalised by taking into account the average total number of station stops for each hour, the numbers for which have been provided by Network Rail. Number of station stops per hour was only obtained from 2012 data, but for the purposes of this report it was decided that using this normalisation on all yearly data sets was sufficient. Interestingly a peak is not present at the busy time around 1700 hours, which supports the proposal that it is environmental conditions causing an increase in station overruns and not simply increased traffic volume. It can be noted that the 2014 data contains fewer incidents than previous years over the course of the entire day. Station overrun occurrence during these hours, as a percentage of the total overruns during the day, is similar to previous years as shown in Table 2. The incidents that have occurred between 0000 and 0500 have been included but the amount of traffic between these hours is very low and results in a single incident plotting very high up the Y axis.

When rails were inspected after a low adhesion incident, it was often noted whether the track was wet or dry. Figure 3 plots the normalised number of station overruns for each hour of the day, this time splitting up the data into 3 categories of dry, wet and those in which no track condition was recorded. It can be seen that the total number of dry incidents throughout the day is very low compared to the other categories, but with a substantial peak between 0500 and 0900 hours. This supports the previous hypothesis that dew may result in a low adhesion incident and dry before the track can be inspected or that oxides are formed overnight. The smaller peak after 2000 hours could also be caused by dew formation, possibly smaller because of previous traffic preventing oxide layer build-up. The Data used to generate Figures 2 and 3 has been analysed elsewhere to support geospatial analysis of low adhesion events .[8]

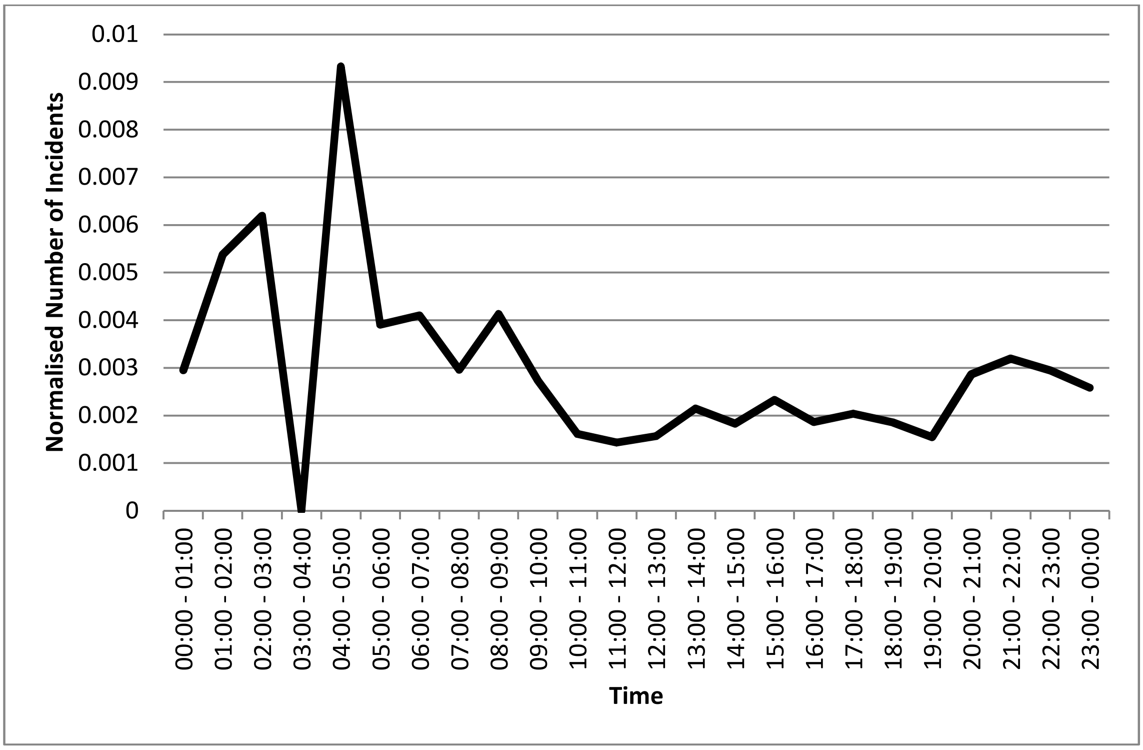

Figure 2. Number of station overruns plotted against hour of the day for 2010-2014, normalised by average number of station stops

	Incidents 0600-1000	**Total Incidents**	**Percentage**
2010	65	167	39
2011	17	47	36
2012	42	147	29
2013	65	217	30
2014	27	90	30

Table 2. Incidents between 0600-1000 hours, as a percentage of total incidents

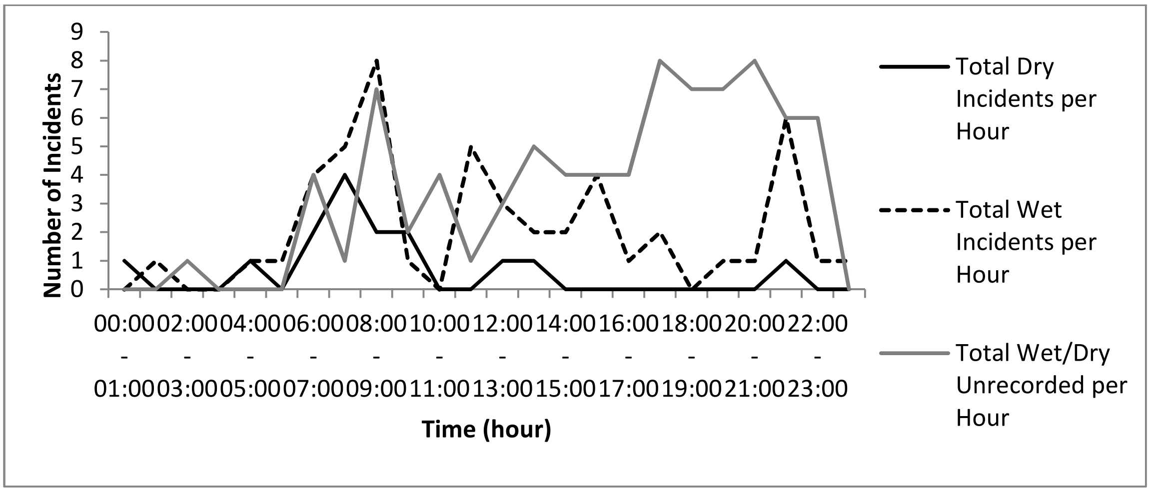

Figure 3. Total wet/dry/unrecorded incidents per hour, during the 2012 autumn season

Incidents per day were plotted over the entire autumn period and are shown in Figure 4. As seen in the prior report, incident numbers rose dramatically on certain days. The most obvious difference in data sets is that the number of station overruns is much lower in 2014 than 2013, with 217 station overruns in 2013 and 90 in 2014. This was out of a total of 397 low adhesion events in 2013 and 215 in 2014, so the percentage of events attributed to weather conditions is similar.

Figure 5 plots the number of incidents per day throughout the autumn season. Also shown are the daily UK average conditions for precipitation, air temperature and wind speed. UK average conditions were obtained by averaging a spread of 31 inland weather stations from across the United Kingdom [5]. This needed further examination using more accurate weather data as conditions across the UK can vary significantly. To achieve this, local weather data was used to narrow down the specific conditions that occur during periods of low adhesion.

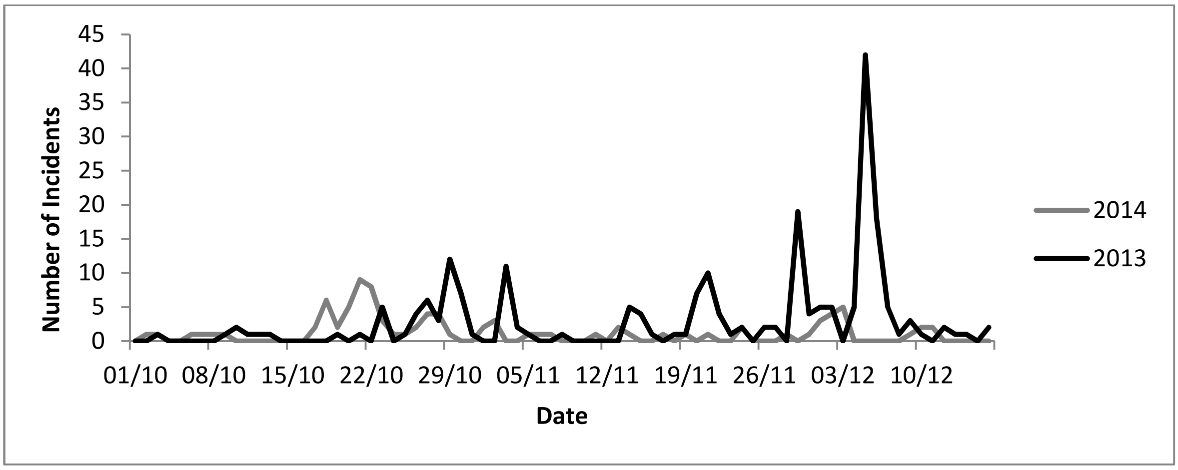

Figure 4. Number of station overruns plotted against date, throughout the autumn season

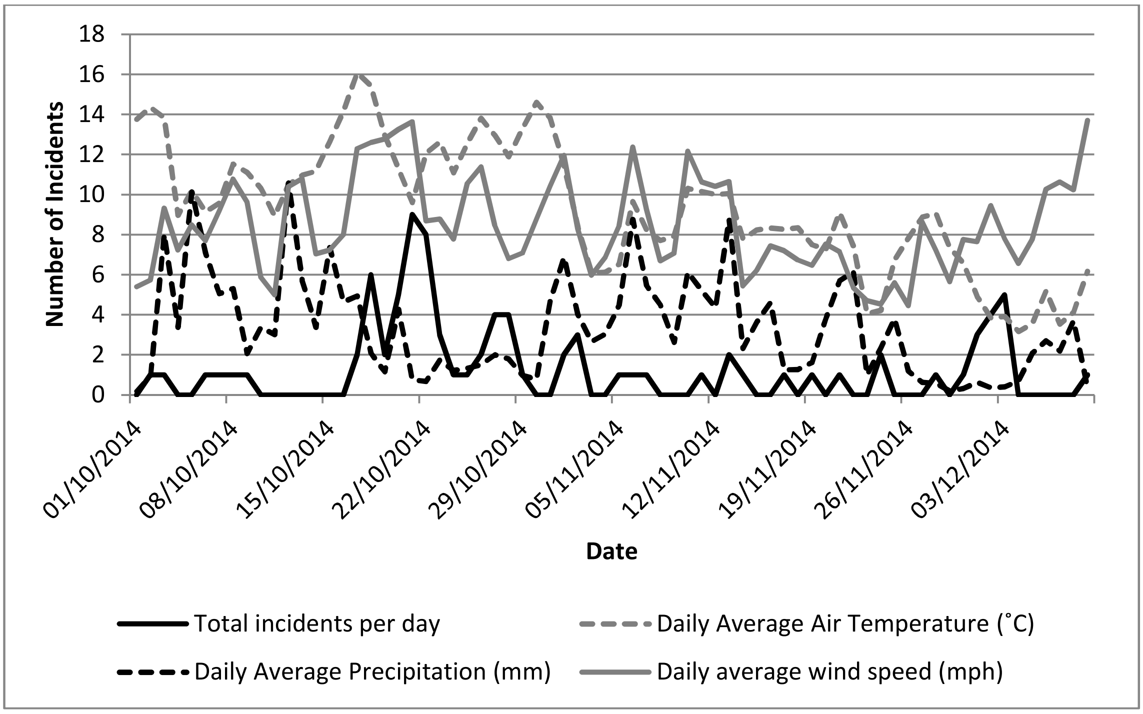

Figure 5. Category of incidents throughout autumn 2014, comparison of the daily average weather data to the total number of incidents

4. Local Analysis

The next stage of this work was to expand upon national level analysis by analysing the weather conditions at the time of incidents on a local scale. This was achieved by linking low adhesion events to their nearest weather station available via SMT weather [5].

Network Rail incidents contained latitude and longitude coordinates which were logged into a map using ArcMap geographical information system (GIS) mapping software, allowing a visual representation of incident positions. The software enabled the viewing of incident locations during a particular time period, which was used for daily, weekly and monthly analysis. ArcMap was used to find specific problem periods and areas, with hourly data from local weather stations sites plotted alongside time of incident.

A number of incidents were plotted alongside their corresponding weather data. One particular period stood out as having a large number of low adhesion incidents, a total of 62 station overruns took place between 05/12/2013-07/12/2013, mostly in the Wessex and Kent areas.

Nearby weather stations available were plotted onto a map in order to find the nearest weather station to each incident. Weather data was plotted against incident time, the weather data was extended before and after the main incident period so that any changes that might cause or prevent these incidents could be observed.

A number of incidents in some locations were seen to be grouped together. Graphs of individual stations were plotted on a number of scales, looking at the weather trends over a long period before focussing on individual problem days. Figure 7 plots the weather data from Wisely and the incident times within a 20 km radius of the weather station have been added. Precipitation data has been multiplied by 10, improving visibility on the graph. Weather data from many other sites was plotted; a graph for Hurn is shown in Figure 8.

Incidents in Figure 7 and 8 seem to be grouped around precipitation. The spread of data points could possibly be due to the onset time of precipitation varying between locations, even if distances are short. Figures 7 and 8 present weather data over a 5 day period, useful to show the weather conditions at the time of incident occurred and clearly showing that precipitation is linked in to some of the low adhesion conditions. The graphs suggest that incidents tend to occur during precipitation or shortly after, but this is unclear due to the hourly resolution. It was also noted that incidents seemed to occur when precipitation was coupled with a large temperature fluctuation; however this may be due to incidents happening in the morning, or due to the weather fronts that bring in precipitation. Whilst it was seen that precipitation has a role in low adhesion conditions in a number of cases, some incidents occur when no precipitation has been recorded. A similar pattern is seen for Figure 9, plotted using 2014 data from Wisely. Incidents are mostly seen grouped around precipitation, but also occurring when a large temperature drop occurs on the evening of 21/10/2014.

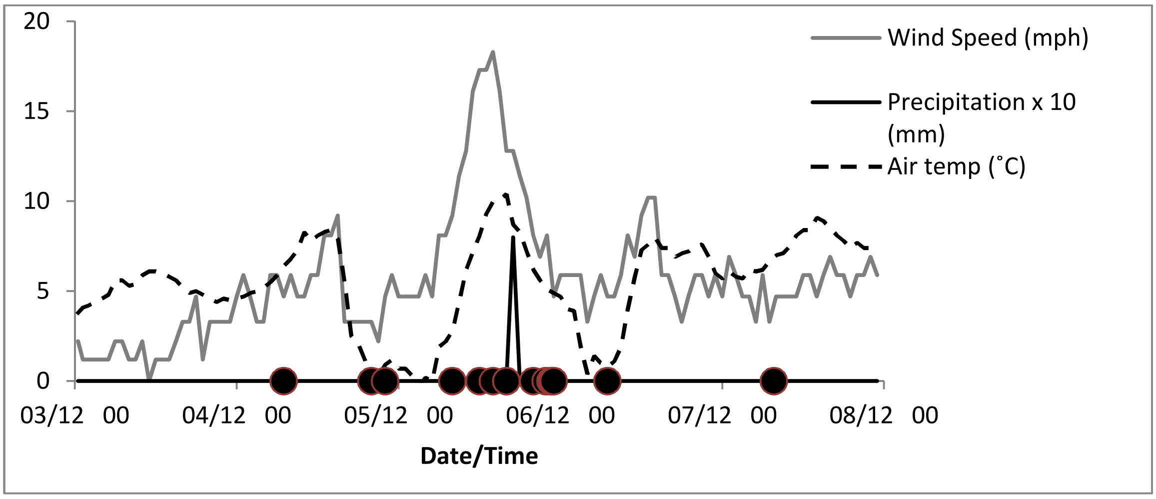

Figure 7. Incidents occurring within 20 km of Wisely, plotted against 2013 Wisely weather data

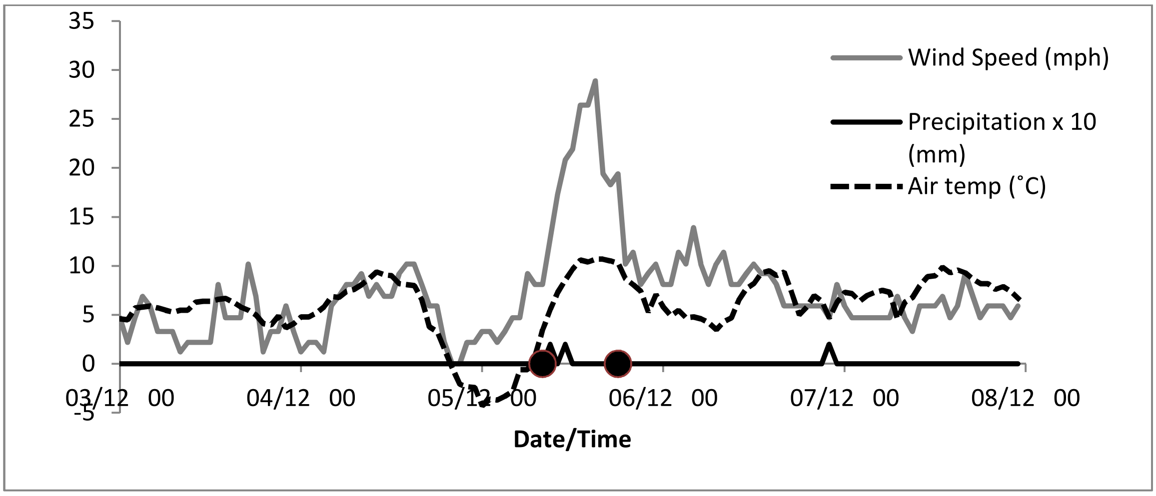

Figure 8. Incidents occurring within 20 km of Hurn, plotted against 2013 Hurn weather data

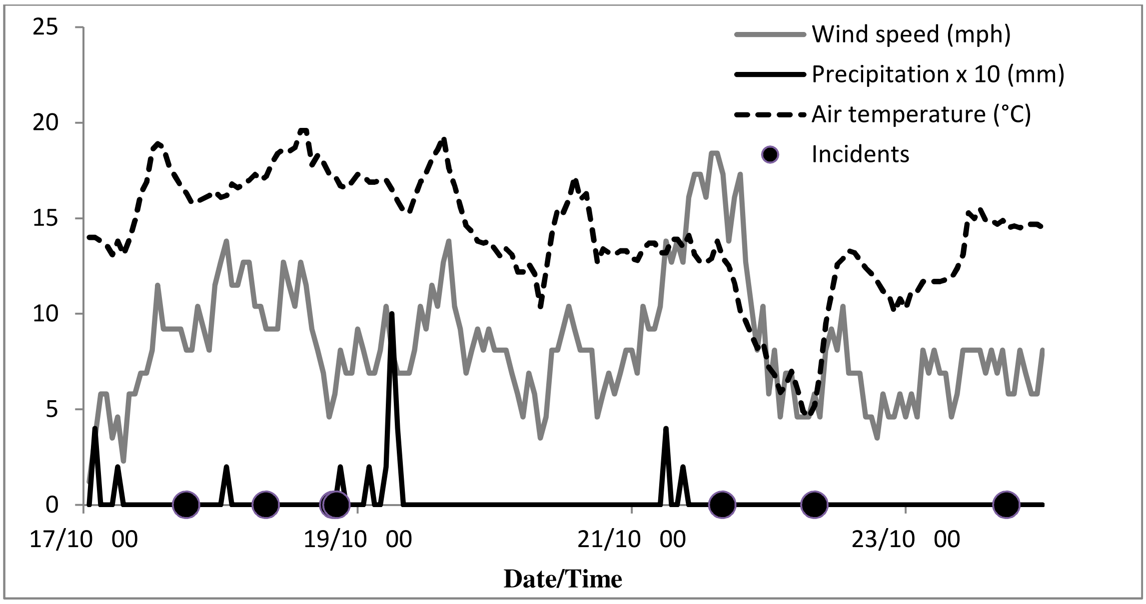

Figure 9. Incidents occurring within 20 km of Wisely, plotted against 2014 Wisely weather data

It was hypothesised that by expanding the time period, the conditions before and after the low adhesion event could be analysed and give an insight into why some conditions resulted in incidents whilst others did not. Figure 10 illustrates this, with incidents near Crosby plotted against weather data over a much longer period of time. The Crosby data also suggests that low adhesion events occur during large temperature fluctuations over the day, with incident groups at the beginning and end of the period having large fluctuations whilst the centre portion has smaller fluctuations and no incidents. These large fluctuations may be caused by clear skies, the large difference between day and night temperatures will cause more dew to be formed. No pattern was found between any change in wind direction and number of incidents. The wind speed is seen to increase during low adhesion periods, although this could be tied in with precipitation falling as a weather front passes, which may also explain the change in temperature.

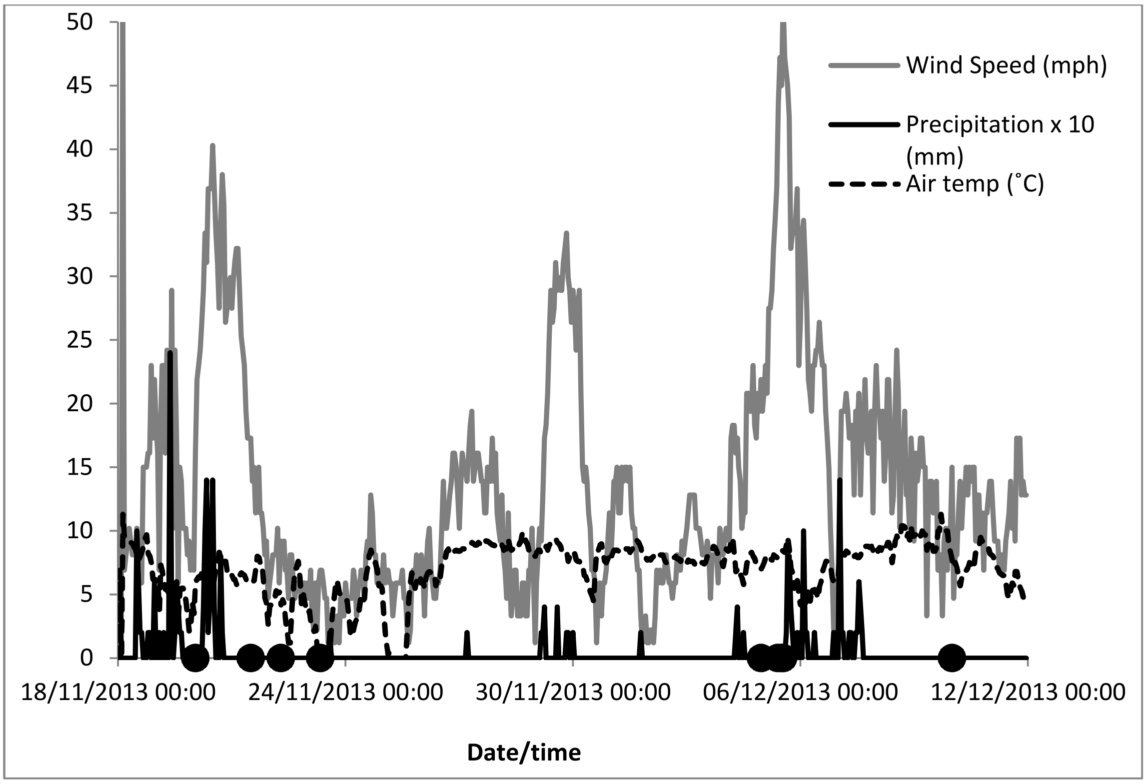

Figure 10. Incidents occurring within 20 km of Crosby, plotted against the corresponding 2013 Crosby weather data

A method of compiling data was needed to fully interpret the results, rather than analysing large numbers of individual graphs. In order to explore the correlation between precipitation and incidents, Figure 11 was produced. Figure 11 categorises incidents into 2 groups: incidents that occurred within 12 hours after precipitation and those where no precipitation occurred for over 12 hours before the incident. The 160 data points from the 2013 and 2014 Network Rail data were chosen because they were close to weather stations, which allowed accurate categorisation. It is obvious using Figure 11 that the majority of incidents are early morning and late at night, however it needs to be noted that this graph has not been normalised, so this could possibly be due to the larger number of station stops during these time periods. Figure 11 does, however, provide a further insight into the cause of these low adhesion events as the ratio of categories will not change with normalisation. Although there are a few spikes, the incidents that involve precipitation are largely spread out evenly throughout the day, perhaps becoming more prevalent around noon. On the other hand, the incidents that did not involve precipitation within 12 hours occur more regularly during the high risk hours between 0600-1800 and 2000-2300. Of all 160 incidents logged in Figure 11, 64 are within 4 hours of precipitation, a further 22 are within 12 hours of precipitation and 74 have no precipitation 12 hours prior to the incident. With only 54% of incidents occurring within 12 hours of precipitation, other factors may play a role in many low adhesion events. The data spread, with incidents not involving precipitation largely prevalent during morning hours, could be due to a number of reasons.

Relative humidity is a measurement of how much water vapour the air can hold, which depends on temperature. At 100% the air is fully saturated so water will condense if the temperature drops, water can also condense on any feature that is cooler than the air temperature. It can be seen that the 12 hour data set follows the average relative humidity throughout the day in Heathrow, shown in Figure 12.

Human factors could be involved. The higher number of station stops and decreased time intervals for trains will put extra pressure on drivers which may result in station overruns caused by late braking. However, this is unlikely due to the nature of the Network Rail data. All station overruns in the data set have been attributed to weather conditions, after it has been established that the neither the driver nor rolling stock are at fault. High pressure water jetting is often used to remove organic leaf matter throughout the autumn season. Tracks are often water jetted at night which could mean that the early trains have to brake on artificially wetted track.

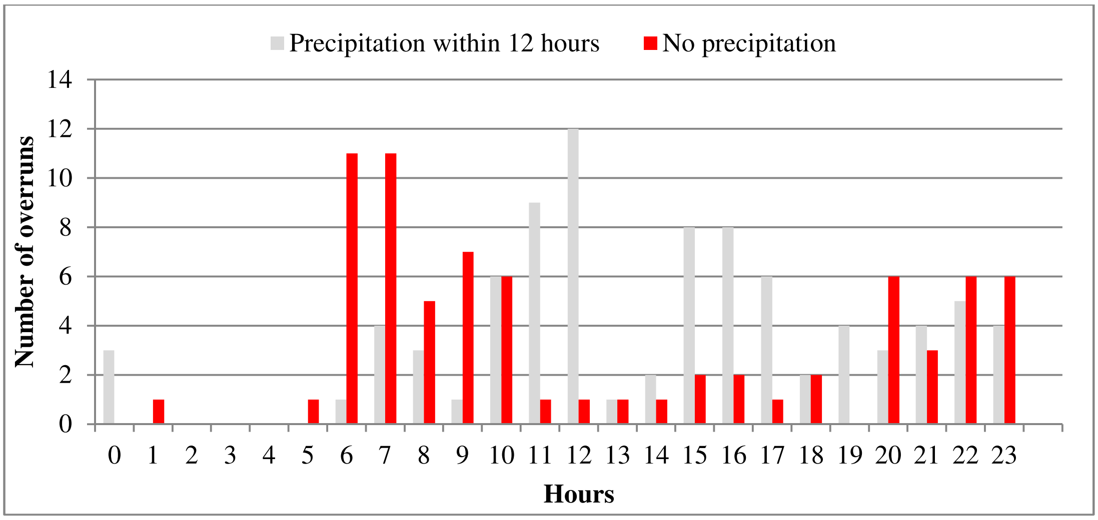

Figure 11. A graph showing the effect of recent precipitation on low adhesion incidents, using 2013 and 2014 data.

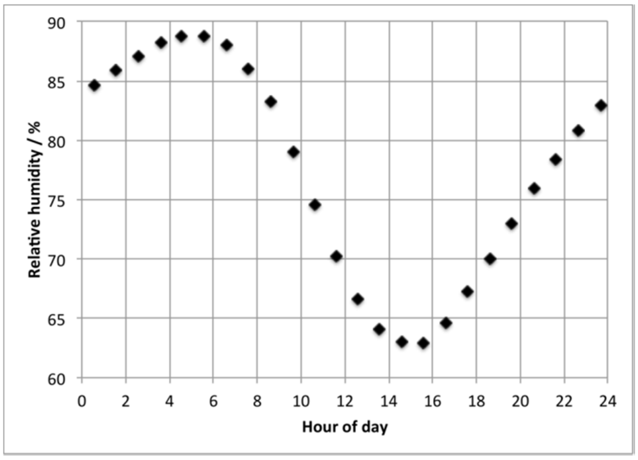

Figure 12. The diurnal humidity at Heathrow, average for a thirty year period 1981-2010 [9]

Correlations between temperature and incidents were looked at using Figure 13. Using SMT weather, the temperature for every hour during the autumn period could be obtained. This was averaged over a number of different sites to obtain average hourly temperature data for the south of England. This was used to find the percentage of time spent at each temperature. The percentage of incidents that took place at certain temperatures was calculated, which was plotted against the percentage of time spent at those temperatures. For instance 6 % of the autumn season was spent at 4˚C, but 18 % of incidents occurred at 4˚C. It can be seen that the number of incidents occurring at temperatures between 4-7˚C are disproportionate to the percentage of time where temperatures were in this range. This is in agreement of the laboratory tests results presented in Zhu et al [4,10], that a lowering of the temperature decreases the friction level both for humidity and water lubricated contacts.

Alternatively the rail head temperature could be the contributing factor to low adhesion, rather than air temperature. The rail temperature change throughout the day has been studied previously [11]. If the rail temperature is lower than the air temperature then the rail will act as a condenser and dew will be formed in humid air. It can be seen from Figure 14, data collected in the course of this work, that the rail reaches its lowest temperature in spring at approximately 0300 hours and the temperature changes dramatically after 0600 hours. The temperature change, shown in Figure 15, from a day in winter show a similar pattern [11], with the rail cooling down quicker, staying colder for longer and reaching as lower peak temperature.

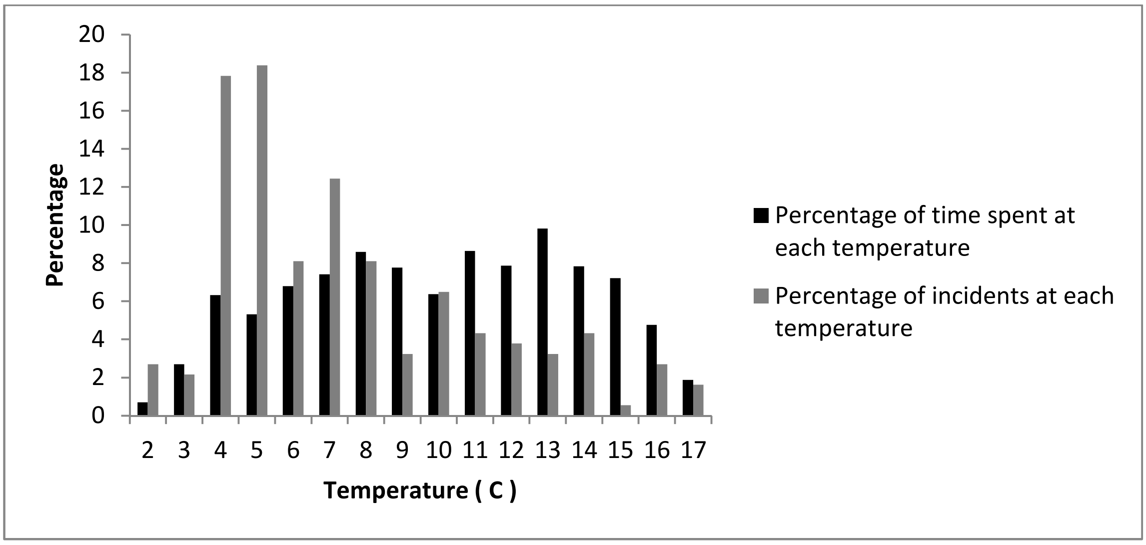

Figure 13. A graph plotting the percentage of incidents that occur at certain temperatures, against average temperatures

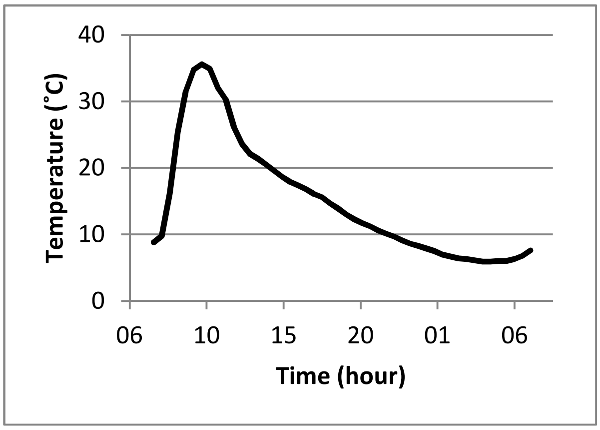

Figure 14. The variation of rail temperature during a sunny spring day

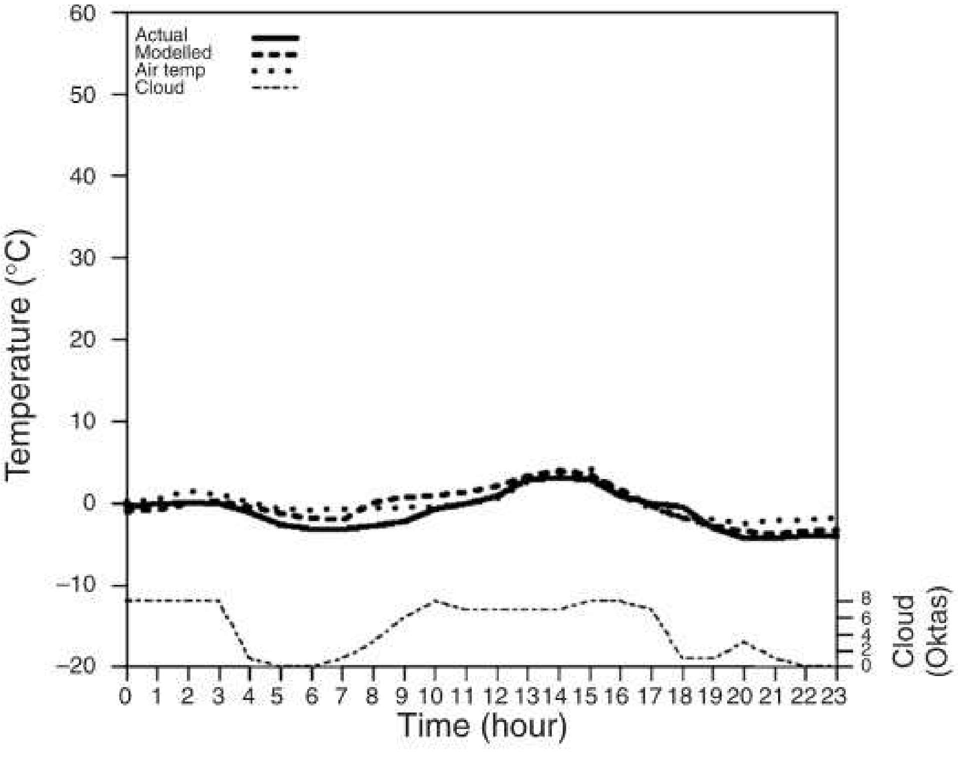

Figure 15. The variation of rail temperature during a day in winter [11]

Temperature data was compiled to look at whether temperature fluctuations resulted in more low adhesion incidents. The derivative for average UK temperature readings throughout the autumn season was plotted alongside station overruns and shown in Figure 16. The results suggest that the station overruns are not dependent on temperature fluctuations as previously proposed but it needs to be remembered that this is based on average air temperature readings rather than location specific railhead temperature readings. This could be due to the temperature fluctuations having little effect unless they lead to a significant change in railhead conditions, for example reaching the dew point.

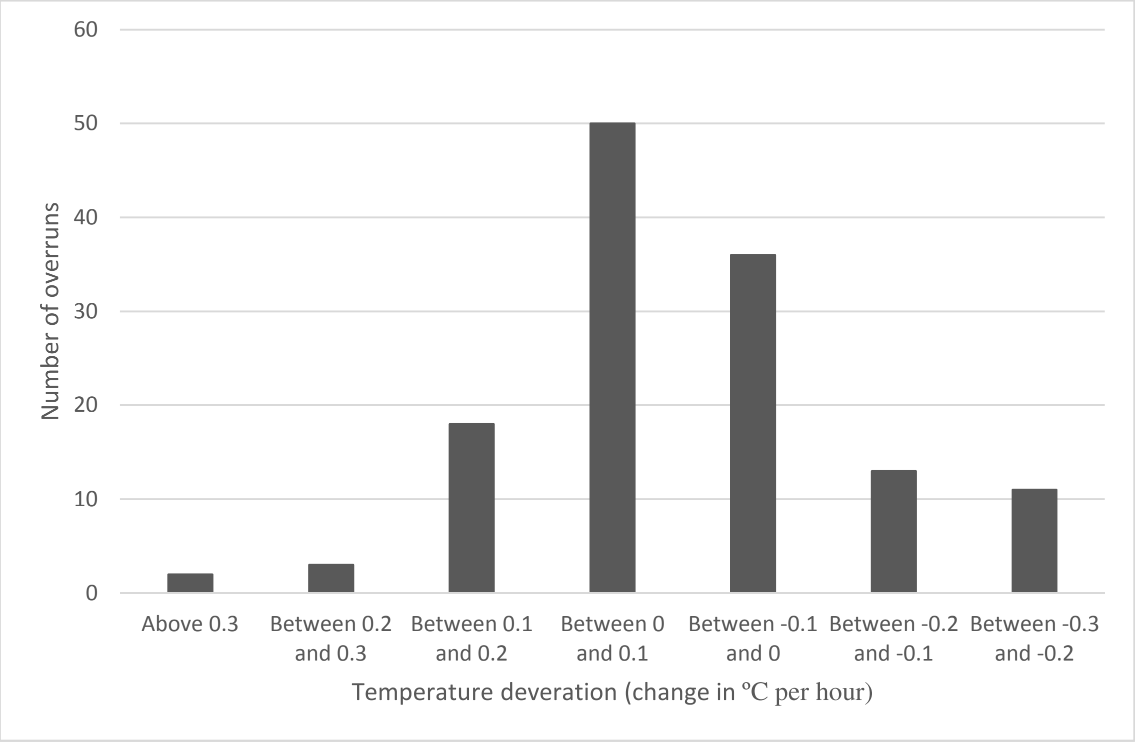

Figure 16. Number of station overruns plotted against UK average air temperature derivation , change in ºC per hour, averaged over 3 hours at time of incident

Current low adhesion methods are based on removing leaf layer contamination. The include on board dispensed sand, wayside applicated traction gels and maintenance trains. All of these techniques focus on cutting through the railhead leaf layer to remove the cause of low adhesion but there is no evidence that these techniques will be effective during wet rail conditions. The wet rail phenomenon is currently unpredictable which may mean any successful mitigation methods also have minimal impact, a better understanding of how and when it happens is needed to mitigate the problem successfully.

5. Stockholm Case study

Stockholm weather conditions in October 2006 were analysed and linked to a period of low adhesion between the 26th and 29th October in the Stockholm underground. Stockholm underground is divided into three lines, one is completely run in a tunnel environment and the other two are partially run in open air and thus subjected to a larger variation in environmental conditions. A substantial increase in the number of vehicles out of service due to wheel flats, often attributed to low adhesion, could be noted for the vehicles operating on the two lines run in open air, see Figure 17. Data from a track based weather station is presented in Figure 18. The wheel flat period included a period of higher than average rains and mist, strong winds, decreasing temperature, and finally ice and frost as summarized in Figure 19. These results are in agreement with the results presented in Figure 13 that more incidents are reported for temperatures 4-7˚C.

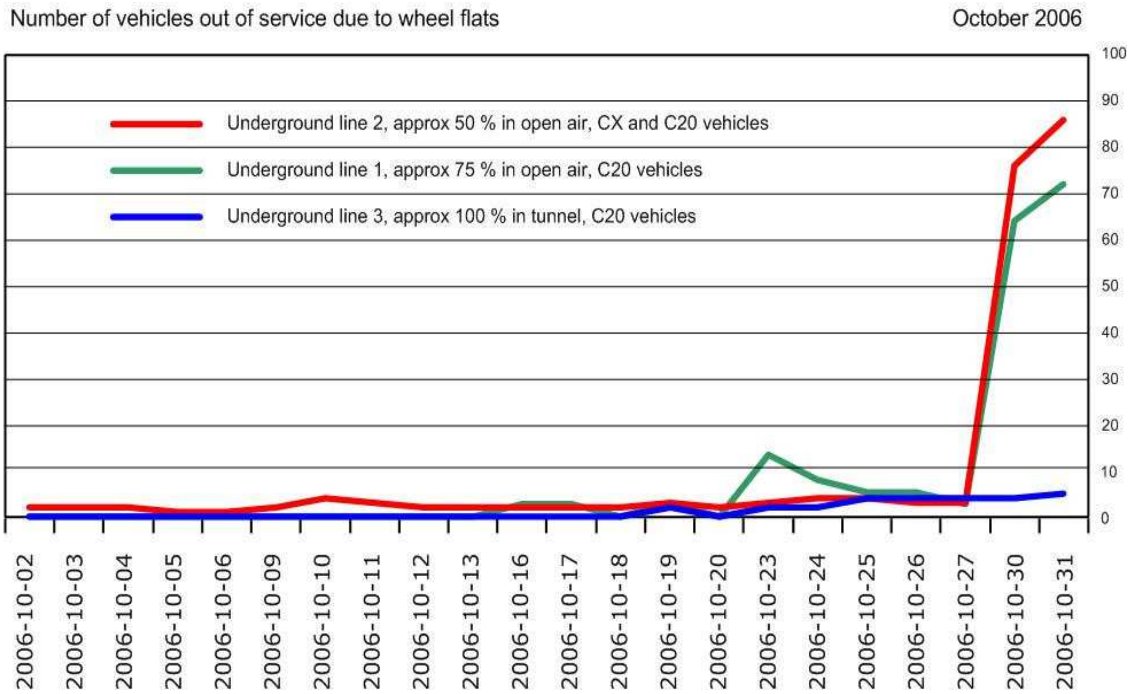

Figure 17. Number of wheel flats during October 2006

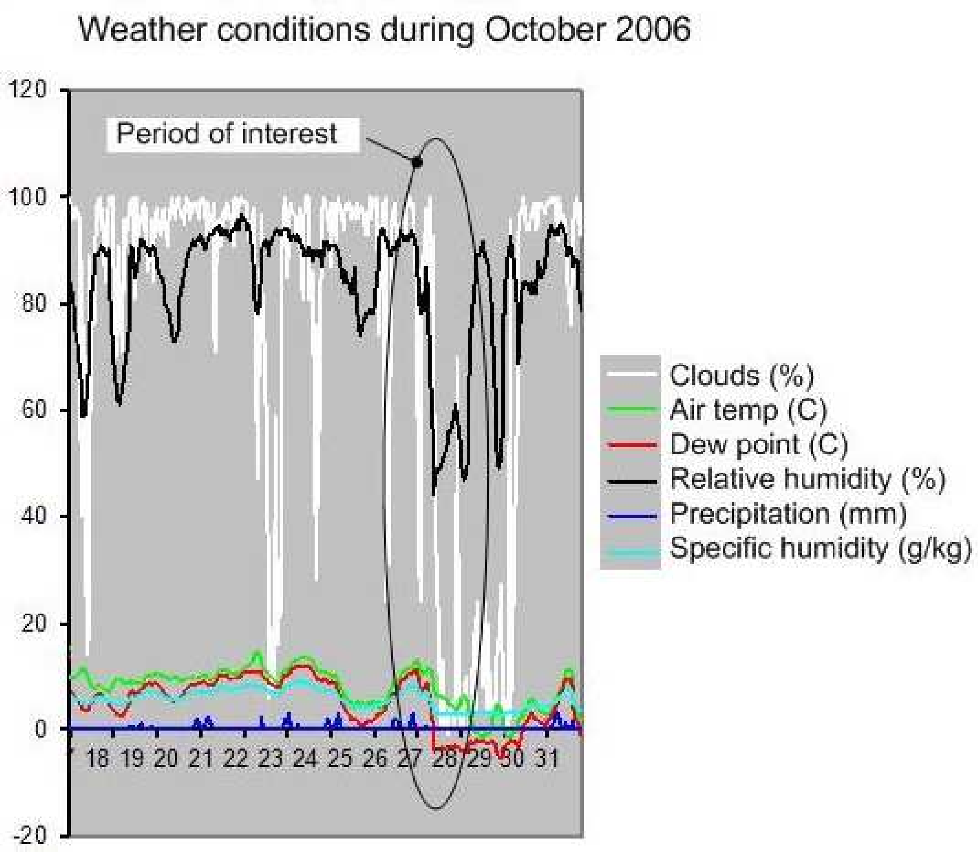

Figure 18. Weather conditions during October 2006

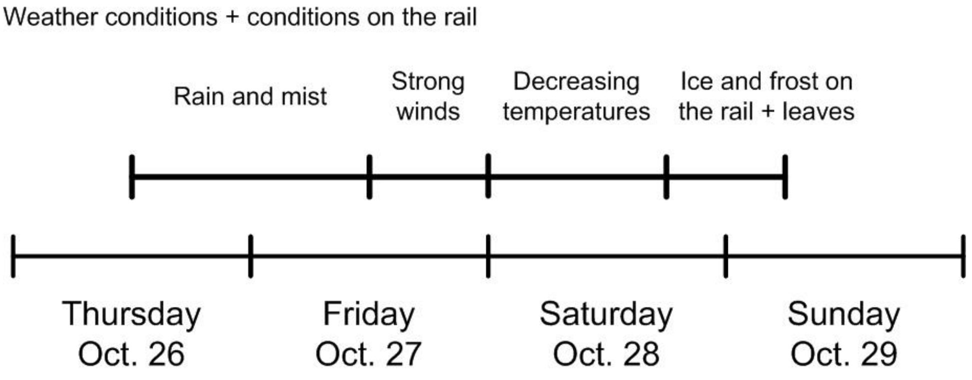

Fig 18. Summary of the weather conditions during the period of increasing number of wheel flats

6. Conclusions

The addition of 2013 and 2014 data to the previous study [3] emphasised the key trends found, notably the high number of incidents during the hours of 0600-0900 and the large number of incidents that occur in seemingly uncontaminated conditions. After mapping the Network Rail data, incident grouping could be seen around certain regions on certain dates. Individual analysis of problem periods, shown in Figures 7-10, were able to provide an insight into the conditions that may lead to low adhesion incidents occurring, notably the tendency for incidents to occur around precipitation and large temperature fluctuations. These results are also in agreement with a Stockholm Underground case study of wheel flats and furthermore supported by previously presented laboratory studies of the temperature influence of friction and adhesion during humidity or water lubricated conditions [4,10].

The precipitation data from various sites was shown visually in Figure 11. It shows a strong link between precipitation and low adhesion incidents between 1100 and 1700 hours. Many more incidents occur in the morning and evening that do not seem to correlate to any precipitation. These incidents also closely match the average diurnal humidity graph, Figure 12, which supports the hypothesis that dew may be involved.

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