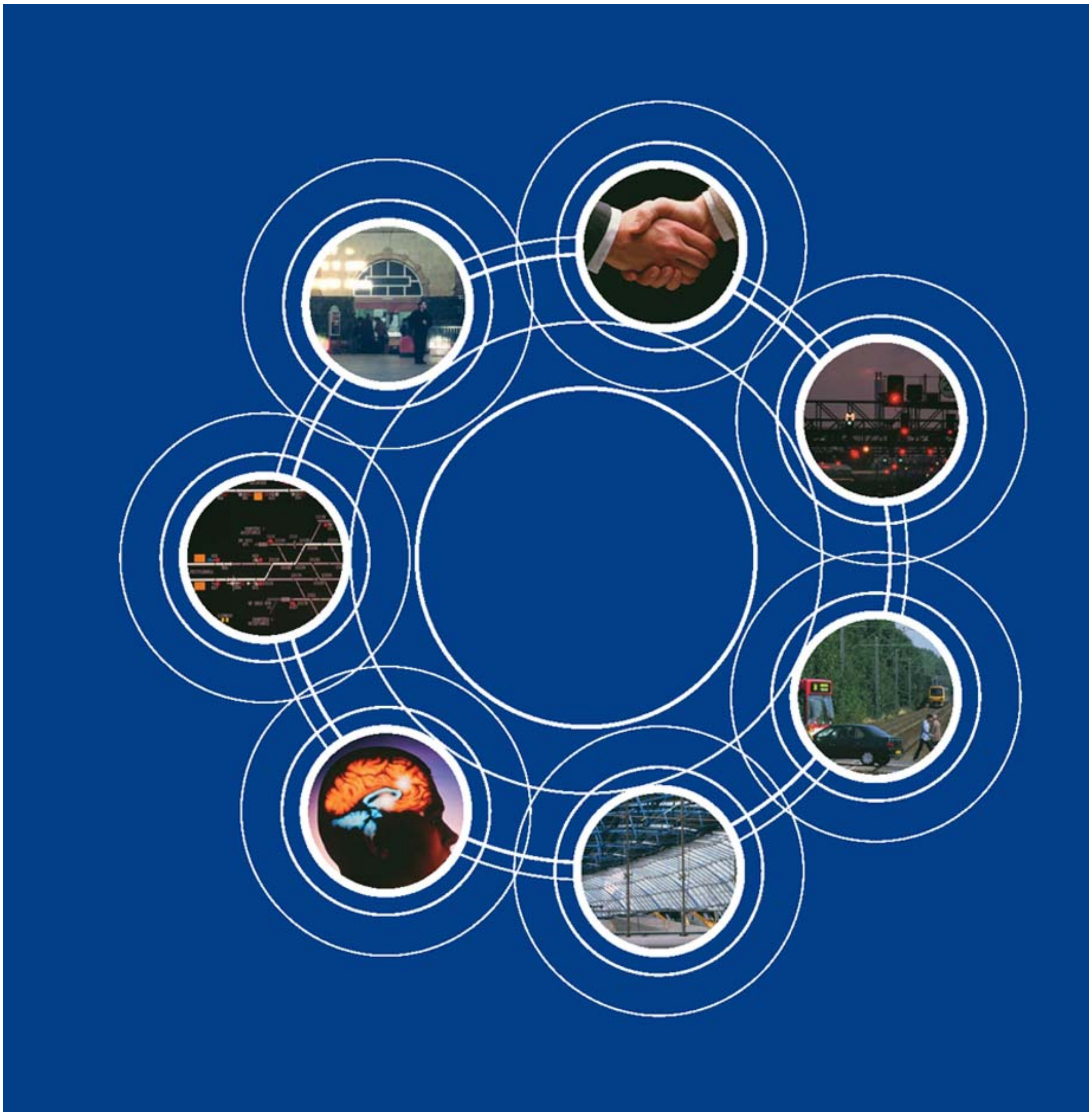
Research Programme

Engineering

The assessment of anemometer-based wind alert systems for implementation in GB: Operational context and requirements



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Written by:
John Easton, David Jaroszweski, Andrew Quinn, Lee Chapman, Chris Baker
The Birmingham Centre for Railway Research and Education (BCRRE), University of Birmingham

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The assessment of anemometer based wind alert systems for implementation in GB

Operational context and requirements

Executive summary

Project T1020 aims to devise an approach whereby speed restrictions may be imposed in localized areas rather than on a blanket basis, before being lifted in response to locally observed (rather than forecast) weather conditions. It is believed that this will help to minimise overall delays to traffic on the rail network, while ensuring that the speed restrictions needed to mitigate increased risk of dewirement during high winds can still be applied. The project consists of 2 main work packages (WP01 and WP02), with the first work package focussing on establishing the operational context and technical requirements for the wind speed alert system, while the wind speed alert algorithms themselves are expected to be developed in the second work package.

Although the responses to high wind speeds on the UK rail network are documented in several standards, the presence of live wind speed monitoring equipment on various routes was known by railway stakeholders to introduce a certain amount of variability into the process as used in practice around the country. With this in mind, a 2-pronged approach to establishing current practice was adopted by the project team, with a review of the formal process as described in the national standards being supplemented by stakeholder interviews with staff from the route control rooms on LNE, LNW and Anglia routes.

The study resulted in the following recommendations:

- Work should take place to establish if alternative speed limits in response to high wind speeds could be allowed in areas of the rail network where the risk of debris on track is low. This work should include a comprehensive review of the reasoning behind the current restrictions.
- With the delivery of live wind speed data it should be possible to automate some, if not all, of the wind speed alert process on the understanding that local engineering staff retain ultimate control over the precise triggering conditions used at each site. Work should take place to investigate:
    - Mechanisms by which information on short-term, localised speed restrictions can be delivered to drivers in a reliable yet timely fashion.

- The feasibility of feeding wind speed alert information directly to traffic management systems thus reducing the need for operator intervention.
- Mechanisms for the delivery of information on delays due to high winds to passengers, including the expected impacts on their journey and accurate estimates of the extent of the disturbance.

- The data that will be gathered by the weather station network represents a rich source of information that will be invaluable to researchers attempting to understand the whole-system impact of extreme weather events on the UK rail network. Work should be performed to establish how this data can best be archived for future use by both the industry and the wider research community.

The assessment of anemometer based wind alert systems for implementation in GB:

Operational context and requirements

Background

RSSB research project T346 noted that: 'Wind speeds on Network Rail OLE electrification infrastructure are monitored by means of dedicated anemometer sites and/or professional meteorological information providers. Service speed restrictions are imposed where wind speeds exceed predetermined levels of average and peak (gust) conditions, in order to mitigate the increased risks of dewirement incidents.' The T1020 research project is a response to the findings of that study and aims to devise an approach whereby speed restrictions may be imposed in localized areas rather than on a blanket basis, before being lifted in response to locally observed (rather than forecast) weather conditions. It is believed that this will help to minimise overall delays to traffic on the rail network, while ensuring that the speed restrictions needed to mitigate increased risk of dewirement during high winds can still be applied. The project consists of two main work packages (WP01 and WP02), with the first work package focussing on establishing the operational context and technical requirements for the wind speed alert system, while the wind speed alert algorithms themselves are expected to be developed in the second work package.

Scope and objectives of work

This document presents the findings of WP01 of the T1020 project. The work package was intended to establish the operational context for the wind speed alert system based around a planned national network of weather stations being procured by Network Rail. In researching this area the project team would draw on the national standards documents and the expertise of route control staff in areas known to have different operational needs with regards to live wind speed information, as well as specialist knowledge of highly localised weather forecasting approaches and the wind speed alert processes used by other transport modes.

The work package aimed to:

- Employ experts knowledgeable in this area in order to assess the wind data that is available, both from NR sources and externally, and define how these should be used as a trigger for wind restrictions against wind speed threshold data;

- Accurately define the requirement for wind-alert systems for the railway, reviewing and taking into account current speed restriction procedures and the reasons that these are applied;
- Provide a UK map showing local OLE design (and by extension identify areas that would be subject to speed restrictions that result from OLE design constraints);
- Understand both NR weather management tool and NR GIS viewers and develop an appropriate solution to implement wind alert system requirements that can be integrated into the current NR architecture;
- Work with the route staff to develop concept interface screens for the display of key information to operational users.

A note on the planned weather station network

At the outset of the T1020 project, Network Rail planned to install around 800-1000 weather stations around the UK rail network, giving information on local conditions to a resolution of around 20 miles. The first 120 stations were in the process of being installed in Scotland and would join the weather monitoring equipment already used by Network Rail, which includes a small network of similar stations in East Anglia, 22 anemometers on the LNE route and a small number of nationally operated stations. The T1020 project aimed to specify and prototype the algorithms that would be used, in conjunction with the weather station network, to provide localised wind speed alerts and associated speed restrictions. The new weather station network was to be provided by MeteoVue, although the purchase of that company may now mean the final station network is of a different scale. At the time of writing the precise state of discussions is unknown.

Structure of the document

This document is separated into 12 sections.

In section two, the authors describe the current approaches used to decide whether emergency speed restrictions need to be put in place as a result of high wind speeds. This section includes the outcomes of the stakeholder interviews with staff from the LNW, LNE and Anglia routes.

Section three discusses the impact of high winds on the OLE and is based on discussions with one of Network Rail's OLE engineers. The section includes information on the distribution of OLE around the UK rail network, the cause of known issues with the OLE in East Anglia and the North East of England, and the impact of the change in height on wind speeds. The latter is required in order to understand the relationship between wind speed thresholds used with ground based anemometers and those used as trigger conditions with the national forecasts.

Based on the interviews presented in sections two and three, the project team had become aware that the speed restrictions imposed in response to strong winds were not, in fact, put in place to reduce a risk of dewirement and instead were mitigation to an increased risk of debris on the track. As a result of this, section four very briefly looks at the proportion of the UK rail network located in terrain where debris are likely to exist (urban and woodland), as opposed to open countryside. This is presented in the hope of stimulating debate around the use of speed restrictions based on terrain type as well as wind speeds.

In section five of the document, the authors review the use of live wind speed data as a basis for speed restrictions by the Highways Agency. Of particular interest here is the staged approach to the removal of restrictions, in direct response to the data being received from the anemometer network.

Section six of the document looks at methods for forecasting wind speeds based on locally derived wind speed data; a technique that could offer value to the industry by giving route control teams forewarning of upcoming high wind speeds and of when services can be expected to return to normal operations after restrictions have been put in place.

In section seven, the authors review some publicly available sources of live climate data that could provide additional information to the Network Rail weather station network. While these may not offer huge advantages for wind speed data, which is subject to effects caused by local geography, the sources could offer value by providing data on variables such as rainfall in locations remote from the trackside that ultimately impact on the rail network.

Section eight describes how data from the weather station network could be distributed and used; proposed uses include feeds to the national weather forecaster, route control rooms, and a long term archive used by researchers to better understand the effects of climate on the railway system.

Section nine presents a functional view of how the wind speed alert process might evolve over time due to the use of live wind speed information.

Sections ten and eleven then present the project team's view of how the alert system should look in terms of broad requirements and concept interfaces showing how the data could be presented to users.

The document is concluded in section twelve, which presents a summary of findings and some brief recommendations going forward.

Existing practices

Although the responses to high wind speeds on the UK rail network are documented in several standards, the presence of live wind speed monitoring equipment on various routes was known to introduce a certain amount of variability into the process as used in practice around the country. The following sections outline the process as described in the standards and the variations employed by three of the routes (LNE, LNW and Anglia).

Alerts based on national weather forecasting arrangements

The national weather forecasting arrangements split the country into 22 forecast areas (see Figure 1 sourced from Network Rail [1]), for which the incumbent weather forecasting providers (MeteoGroup at the time of writing this document) deliver daily forecasts with a 4-day look ahead.

Forecasts are delivered by email to Network Rail route control managers at around 03:30 each day, who then assign colour codes to each aspect of the forecast reflecting the level of severity the conditions represent (green, yellow, and red within a single route for most weather conditions; black for railhead contamination due to leaf fall; and double red for a severe forecast affecting more than one route). The colour coded forecast information is circulated to concerned parties on the route by around 05:00. If severe weather is predicted, a route Extreme Weather Action Team (EWAT) conference is called. For extreme weather reported in daily forecasts this conference commonly takes place almost immediately according to route staff, allowing arrangements to be made for the next 24 hours of operations. However, for extreme weather expected beyond a 24-

hour horizon route EWAT times are commonly held at around 10:00 and 15:00 based on information in [2] (see Table 1). Ongoing monitoring of the forecast extreme weather takes place at intervals of no more than 12 hours for weather expected in the next one to two days, or six hours for weather expected in the next 24 hours.

Figure 1 - The 22 weather regions used by Network Rail.

Table 1 - Route EWAT conference times for severe weather predicted in the future. Reproduced from [2]

Network Rail Route EWAT Schedule										PA Updated 280110		
Hour	0800	0900	1000	1100	1200	1300	1400	1500	1600	Summary		
Minutes												
Scotland			30					30		1030	&	1530
LNE												
GN								15				1515
NE												1500
LNW												
Central												1100
Midlands				30								1130
M&C												1200
Anglia			30							1030	&	1500
Wessex										0900	&	1500
Sussex							30			0930	&	1430
Kent								30		1100	&	1530
Western										1100	&	1400
National										1000	&	1600

The severity of high winds is defined at the national level, along with the appropriate speed restrictions (see Table 2). If high wind speeds are predicted in the national forecast, the EWAT will impose a blanket emergency speed restriction (ESR) on the sections of the line likely to be effected. Unlike a normal ESR that is imposed in a localised area with temporary marker boards, blanket emergency restrictions are not signed at the lineside and therefore tend to run between features that are obvious to the drivers, such as two stations. This may result in an ESR being imposed over a significant distance (for example 40 miles between Preston and Oxenholme) and lead to a significant disruption to overall performance and a large number of attributed delay minutes being built up. The EWAT will also make decisions regarding Network Rail's other responses to the high wind speed event, such as arranging for additional maintenance staff to be on duty.

Table 2 - High wind speed triggers and responses

Wind Speed	Action	Colour Code
Forecast gusts <= 59 miles per hour	No action	Green
Forecast gusts 60 to 69 miles per hour	Be aware of possible restrictions	Yellow
Forecast frequent (one per 10 min period minimum) gusts 60 to 69 miles per hour sustained over 4 hours	50 miles per hour speed restriction after the first 4 hours unless number of reported incidents requires immediate action	Red
Forecast gusts >= 70 miles per hour	50 miles per hour speed restriction	Red
Gusts >= 90 miles per hour	Services suspended	Red

Following the EWAT conference the route control manager will then feed information on its decisions to other stakeholders on the route (such as passenger train and freight operators), this is usually takes place within an hour of the conference.

Delivery of emergency speed restriction information to drivers

Information on emergency speed restrictions is circulated to drivers in a number of ways, largely depending on which is most appropriate given the timescales involved. Methods used to distribute information on extreme weather to drivers include the insertion of notices in the driver's bag / late notice case (if the restriction is either in place or already scheduled to be imposed before the shift starts), distribution of notices to the drivers at scheduled platform stops, signallers stopping trains at signals, and radio messages to drivers in an area via the National Radio Network (NRN) or the Global System for Mobile Communications - Railway (GSM-R).

Live wind speed information

The use of live wind speed information to support the national forecast is not a required part of the high wind speed alert process. For this reason, both the extent to which live data is used and the processes involved vary from route to route.

Live measurement of wind speeds

Live wind speed measurements on the UK rail network are obtained via one of two main channels, either as feeds from the Met Office national weather station network accessed via the national forecast provider, or more directly from railway operated anemometers. In the latter case, the anemometers are either installed on the catenary or form part of a more comprehensive weather station located at the trackside.

Usage of live wind speed data across the network

To obtain an indication of the extent of live wind speed data usage around the UK rail network, the team has visited three route control centres: LNW in Manchester, LNE in York, and Anglia in London. The routes were selected based on a combination of either:

1. Known OLE issues in which high wind speeds are thought to be a contributing factor (Anglia and LNE); or,
2. Known differences in operational responses to high wind speeds (Anglia, LNE and LNW).

LNW

Of the 3 routes visited, LNW (L&C and CEN weather regions) relies most heavily on the national forecast for wind speed information, supplementing it solely with additional forecast and live data from a small number of non-railway-owned weather stations accessed through MeteoGroup's Seasons Management Team (SMT) weather portal. While located in the same geographical area as the track they relate to, these stations are frequently not sited in very close proximity to the railway and can, therefore, only give an indication of weather conditions in the area, at least in the general case.[1] This is particularly true for wind speed and direction, which can be highly localised due to the effects of geographical features and the presence of buildings.

Live data on the SMT weather site is updated on an hourly basis and includes temperature, wind speed, gust, and precipitation. Surprisingly, despite the remote location of the stations relative to the tracks, the live wind speed data on the portal is considered to be accurate by the LNW route control team, most likely due to the exposed nature of the sites, and is reported to have been measured at within a couple of miles per hour of observed trackside values using hand-held metres on an ad hoc testing basis; despite this, live data is not used directly for imposing

1 A more detailed description of the existing Met Office weather station network, as used by MeteoGroup, and its coverage of the rail network is included later in this document.

speed restrictions on the route. Weather forecasts from the SMT weather site, particularly later in the day, may be more up to date than the morning's national forecast and as a result forecasts from SMT weather (unlike the live data) are occasionally used to inform the high wind speed alert process (particularly in determining when to remove restrictions).

LNE

On LNE, a network of Vaisala weather stations has been in use since around the year 2000. These are mounted on the catenary and provide up to date local wind speed data for 22 sites across the GN1, GN2, NE1 and NE2 forecast areas. Data is available for the previous 24 hours at five-minute intervals and includes speed, direction and maximum gust. Live wind speed data from the network is used by operators to determine whether speed restrictions need to be imposed with reference to a set of defined triggers, as is the case with forecast wind speed data. The relationship between the wind direction and the line of the track is considered to be very important by the route staff, and live data from the anemometers along the route is displayed as a direction indicator overlaid on the orientation of the tracks at the site. The LNE system is configured to notify operators via email if the gust (or average wind speed) value at any given site crosses a 45 miles per hour threshold, and the operator will then decide whether an 80 miles per hour speed restriction should be imposed in the area. The interpretation of the live wind speed data on LNE includes an acknowledged amount of "expert judgement" on the part of operators and the "human in the loop" is considered a very important component of the wind alert system; for example, while the nominal wind speed threshold for the imposition of ESRs used by LNE is 45 miles per hour, an operator using the live wind speed data might wait until several gusts have been recorded as passing the threshold before the speed restriction is imposed, cross wind gusts are taken more seriously than longitudinal gusts along the line of the tracks, and paper notices may not be issued to drivers if the wind speed is only expected to exceed the threshold for a short period. The LNE control room staff were keen to emphasise that while their flexible approach to the interpretation of wind speed thresholds had avoided situations such as the "on / off / on / off" imposition of ESRs when wind speed levels were hovering around a threshold mark (thus minimising delay), the route had never been in a situation where catenary wires had been brought down due to a speed restriction not being applied when it could have been; whether this implies that the speed thresholds as they stand are fundamentally incorrect or that they are correct but include a sensible margin for error is a matter for debate.

Where live measurements of wind speeds are being taken, the data is generally of a much higher granularity than the national forecasts. In order to try and simplify the information presented to drivers on the day, it is common practice for operators to impose speed restrictions across longer continuous sections of a line than are strictly necessary if almost neighbouring areas of track have high wind alerts (eg a red, yellow, red alert pattern exists on a given area of the line). While with the current methods of delivering speed restriction information to drivers route controllers generally believed that very high resolution wind speed alert data may not be useful operationally (the limiting factor being the driver's ability to cope with large numbers of very short, unsigned temporary restrictions), there was an acknowledgement that improved driver advisory systems or in cab signalling would make this a much more practical proposition.

Anglia

Anglia have what is arguably the most advanced system of the routes visited, with a network of MeteoVue weather stations in place that feed into a tailored weather data management platform called RailMet. Data come in from the weather stations in bursts every 15 minutes and are then automatically coloured based on thresholds specified by the route before being delivered to operator screens. By choosing appropriate thresholds, colour codes can be directly related to responses allowing the route team to impose speed restrictions by colour without having to look back at the specific values in the data. Data from any station connected to the system are available historically back to the point at which it was connected to the RailMet system. For operational use, route staff can also subscribe to hourly email alerts for different wind speed thresholds and areas; email alerts include details of the threshold being crossed, the location of the station, the date and time of the event, and unique identifiers for the data allowing an audit trail to be built up, this is critical if route control staff are required to evidence their decisions in the future.

In practice, wind speed thresholds on the Anglia route are currently set at 35, 45, 50 and 55 miles per hour, as specified by the local OLE engineer (note: this is a spread of single values used at different sites not multiple threshold values applied at each site). When these thresholds are exceeded alert notifications are emailed to the flight engineer on duty, who then enacts the appropriate operational responses. Information on restrictions is most commonly passed to drivers via cab secure radio. In the future it is hoped that GSM-R will allow information to be passed to the drivers automatically as the train moves into each signalling berth. An alternative communications option being considered by the route is the use of lineside electronic speed boards, these would display the current wind speed alert level / current allowed speed in an area.

Weather information in RailMet is presented as a time against location matrix as shown in Figure 2.

As with the SMT weather portal used by LNW, detailed weather forecast information is provided to RailMet by MeteoGroup and includes hourly predictions for the next 48 hours. In order to provide a consistent user experience with the live and archived data, this information is colour coded and available within the system for thresholding and the raising of alerts (see Figure 3). Route staff stated that because the forecasts used in the RailMet system were more specific than those supplied nationally, they are allowing more localised speed restrictions (rather than blanket restrictions) to be put in place than would otherwise be possible. This has saved a significant number of delay minutes on the route. (During the meeting it was stated that the improved information paid for the forecast product from MeteoGroup in a single afternoon).

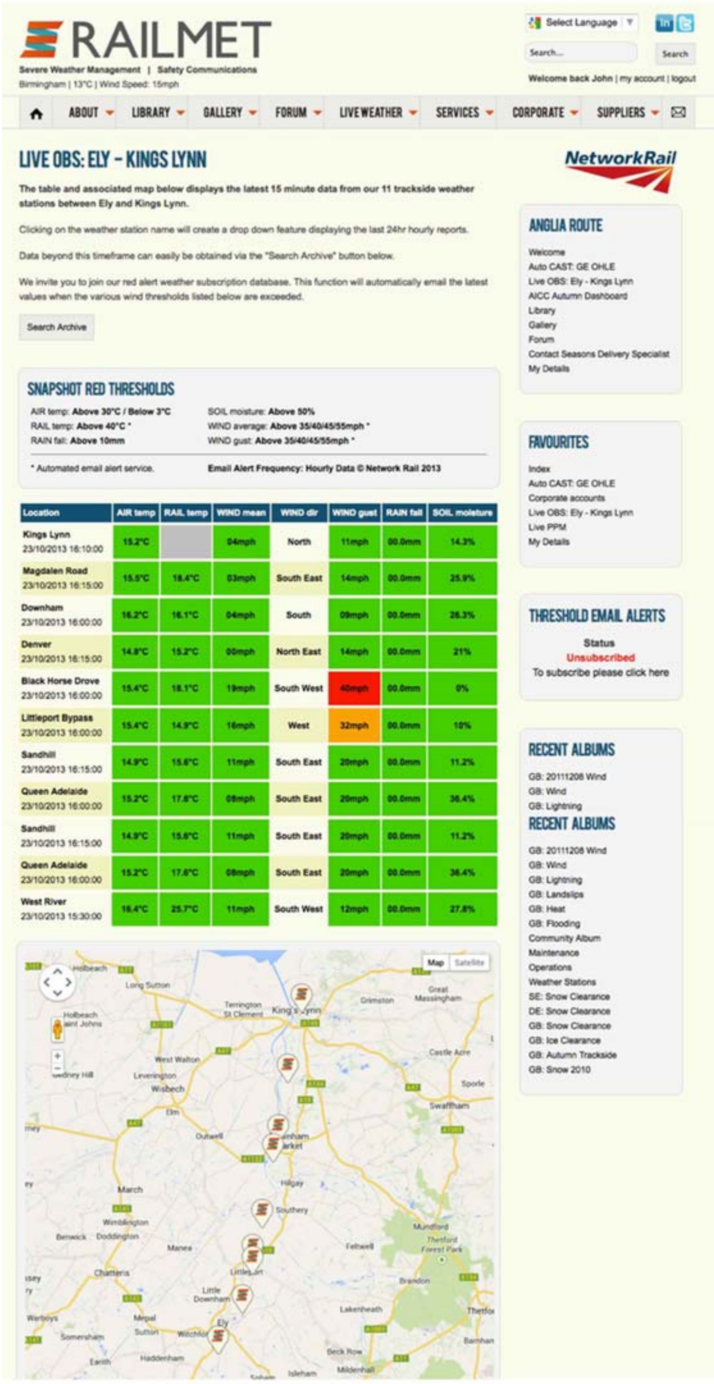
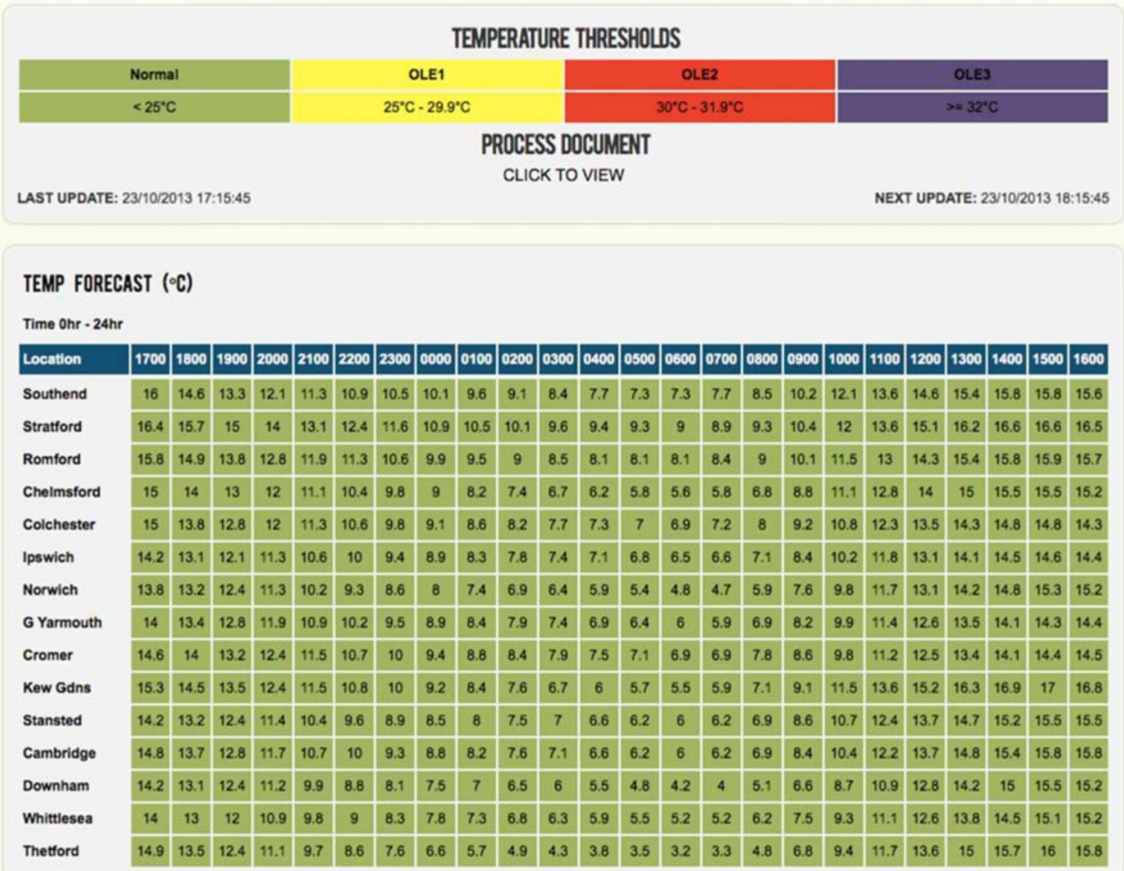


Figure 2 - An example of the RailMet weather observations screen.



TEMPERATURE THRESHOLDS

Normal	OLE1	OLE2	OLE3
< 25°C	25°C - 29.9°C	30°C - 31.9°C	>= 32°C

PROCESS DOCUMENT

CLICK TO VIEW

LAST UPDATE: 23/10/2013 17:15:45

NEXT UPDATE: 23/10/2013 18:15:45

TEMP FORECAST (°C)

Time 0hr - 24hr

Location	1700	1800	1900	2000	2100	2200	2300	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600
Southend	16	14.6	13.3	12.1	11.3	10.9	10.5	10.1	9.6	9.1	8.4	7.7	7.3	7.3	7.7	8.5	10.2	12.1	13.6	14.6	15.4	15.8	15.8	15.6
Stratford	16.4	15.7	15	14	13.1	12.4	11.6	10.9	10.5	10.1	9.6	9.4	9.3	9	8.9	9.3	10.4	12	13.6	15.1	16.2	16.6	16.6	16.5
Romford	15.8	14.9	13.8	12.8	11.9	11.3	10.6	9.9	9.5	9	8.5	8.1	8.1	8.1	8.4	9	10.1	11.5	13	14.3	15.4	15.8	15.9	15.7
Chelmsford	15	14	13	12	11.1	10.4	9.8	9	8.2	7.4	6.7	6.2	5.8	5.6	5.8	6.8	8.8	11.1	12.8	14	15	15.5	15.5	15.2
Colchester	15	13.8	12.8	12	11.3	10.6	9.8	9.1	8.6	8.2	7.7	7.3	7	6.9	7.2	8	9.2	10.8	12.3	13.5	14.3	14.8	14.8	14.3
Ipswich	14.2	13.1	12.1	11.3	10.6	10	9.4	8.9	8.3	7.8	7.4	7.1	6.8	6.5	6.6	7.1	8.4	10.2	11.8	13.1	14.1	14.5	14.6	14.4
Norwich	13.8	13.2	12.4	11.3	10.2	9.3	8.6	8	7.4	6.9	6.4	5.9	5.4	4.8	4.7	5.9	7.6	9.8	11.7	13.1	14.2	14.8	15.3	15.2
G Yarmouth	14	13.4	12.8	11.9	10.9	10.2	9.5	8.9	8.4	7.9	7.4	6.9	6.4	6	5.9	6.9	8.2	9.9	11.4	12.6	13.5	14.1	14.3	14.4
Cromer	14.6	14	13.2	12.4	11.5	10.7	10	9.4	8.8	8.4	7.9	7.5	7.1	6.9	6.9	7.8	8.6	9.8	11.2	12.5	13.4	14.1	14.4	14.5
Kew Gdns	15.3	14.5	13.5	12.4	11.5	10.8	10	9.2	8.4	7.6	6.7	6	5.7	5.5	5.9	7.1	9.1	11.5	13.6	15.2	16.3	16.9	17	16.8
Stansted	14.2	13.2	12.4	11.4	10.4	9.6	8.9	8.5	8	7.5	7	6.6	6.2	6	6.2	6.9	8.6	10.7	12.4	13.7	14.7	15.2	15.5	15.5
Cambridge	14.8	13.7	12.8	11.7	10.7	10	9.3	8.8	8.2	7.6	7.1	6.6	6.2	6	6.2	6.9	8.4	10.4	12.2	13.7	14.8	15.4	15.8	15.8
Downham	14.2	13.1	12.4	11.2	9.9	8.8	8.1	7.5	7	6.5	6	5.5	4.8	4.2	4	5.1	6.6	8.7	10.9	12.8	14.2	15	15.5	15.2
Whittlesea	14	13	12	10.9	9.8	9	8.3	7.8	7.3	6.8	6.3	5.9	5.5	5.2	5.2	6.2	7.5	9.3	11.1	12.6	13.8	14.5	15.1	15.2
Thetford	14.9	13.5	12.4	11.1	9.7	8.6	7.6	6.6	5.7	4.9	4.3	3.8	3.5	3.2	3.3	4.8	6.8	9.4	11.7	13.6	15	15.7	16	15.8

Figure 3 - A typical forecast screen from RailMet.

While MeteoVue have provided the weather stations on the Anglia route, RailMet itself is a general weather data integration platform and information from a wide range of weather stations or other sources could be integrated. This may present a convenient way to both integrate information from existing investments (LNE Vaisala) into the new national weather station network, and to combine Network Rail owned data with data from external agencies such as the Highways Agency under a mutual data sharing arrangement.

A scrolling “weather ticker” is the next step for the Anglia route system, displaying useful weather information for the day, along with a daily dashboard including CCTV allowing remote inspections of key sites (railhead contamination etc.). An iPad friendly extension to the system, the Anglia Weather Information system, was due to be launched in early October 2013.

In a variation to practices on the other routes, Anglia have opened their information on the RailMet platform to the train operators on the route; the intention behind this is to help convince stakeholders that Network Rail are doing everything within their power to avoid imposing unnecessary restrictions. Anglia are also much more in favour of a fully automated system than the other routes interviewed. They adopt a completely “black and white” approach to the speed restrictions and therefore have little operational interest in a “human in the loop”, although the input of human engineers at the planning / threshold setting stage is something they are very keen on maintaining. If nothing else, it is hoped that the procedure based approach will help the relationship between Network Rail and other stakeholders by ensuring that decisions are consistent and not based on an interpretation of the incoming data by operational staff.

Frequency of high wind speed events and alerts

It is worth noting that the imposition of blanket speed restrictions due to high wind speeds is not a common event on the rail network; LNW control room staff estimated that they were used on only five or six occasions in an average year for that route, and LNE staff had not needed to use them at any point during the summer of 2013. Despite their infrequent application however, blanket restrictions do represent a significant cost to the industry with figures passed to the project team indicating that blanket speed restrictions for heat or high winds resulted in nearly 20,000 delay minutes and a Process for Performance Improvement (PfPI) cost of over £610k in 2011 (see Appendix A). Placed in a wider context, Network Rail [3] have reported that 817,269 delay minutes were attributed to severe weather over the period, meaning that blanket speed restrictions due to heat or high winds represented around 2.3% of the total severe weather delays. This percentage is likely to be smaller than it would be in an average year due to unusually severe winter conditions in November / December 2011.

The impact of high winds on OLE

Unexpectedly, the project team's visits to the route control centres had suggested that the imposition of blanket ESRs of 50 miles per hour in response to high wind speeds may be based on an increased risk of debris on the track rather than an increased likelihood of pantograph blow off. In an attempt to clarify this point, a meeting was arranged with one of Network Rail's OLE specialists; to a large extent, this section is a summary of the outcomes of that meeting but also includes other information on the OLE designs in use around the UK rail network.

OLE designs in use on the UK rail network

A range of different styles of OLE is in use around the UK, strung with either copper or steel reinforced aluminium wires (although the latter are being replaced due to difficulties splicing the composite cable). Information on the current distribution of OLE equipment around the UK rail network is hard to find, although Mk3b is widely held to be the most common system. Network Rail staff interviewed by the project team have suggested that the knowledge of exactly which style of OLE is used on each of the routes may only be available within the routes themselves, particularly in the case of any potential problem areas where wires are known to be poorly aligned with the track. A national database of this information was suggested as having value to the industry during the stakeholder interviews. In the absence of more up to date data, the project team has relied on the findings of RSSB project T346, which reported on the OLE systems in use around the country in 2007. A map summarising the findings is shown in Figure 4 and was used as the basis for the online interactive route map compiled by the project team. An example image from the interactive map can be seen in Figure 5 where the web application is displaying the location of all overhead electrified lines.

The relationship between high winds and dewirement

High winds alone were not seem as being a currently significant cause of dewirement or blow off by the OLE engineer questioned, although a combination of incorrectly aligned track, excessive vehicle body sway and high winds was believed to be much more likely to result in difficulties; this is because these factors can cause the pantograph to move further than it should, that is to say the locus of movement of the pantograph is either greater than intended or offset in space relative to the catenary wires.

Normally, designed tolerance for the alignment between the track and the wires was stated as being +/- 25 millimetres. One major contributing factor to problems of this type was seen as being the lack of clear communication between permanent way teams and the OLE engineers, with the track being moved the allowed 25 millimetres on a single occasion (for example when tamping is taking place) but this information not being passed to the OLE teams and the track subsequently being moved another 25 millimetres resulting in a compound problem. Big problems involved with the wind and OLE are mostly about plastic bags or builders' plastic sheeting, which can get caught around the support structures or the pantographs resulting in damage. Another is overgrown vegetation that is being moved by the wind interfering with the catenary wires themselves.

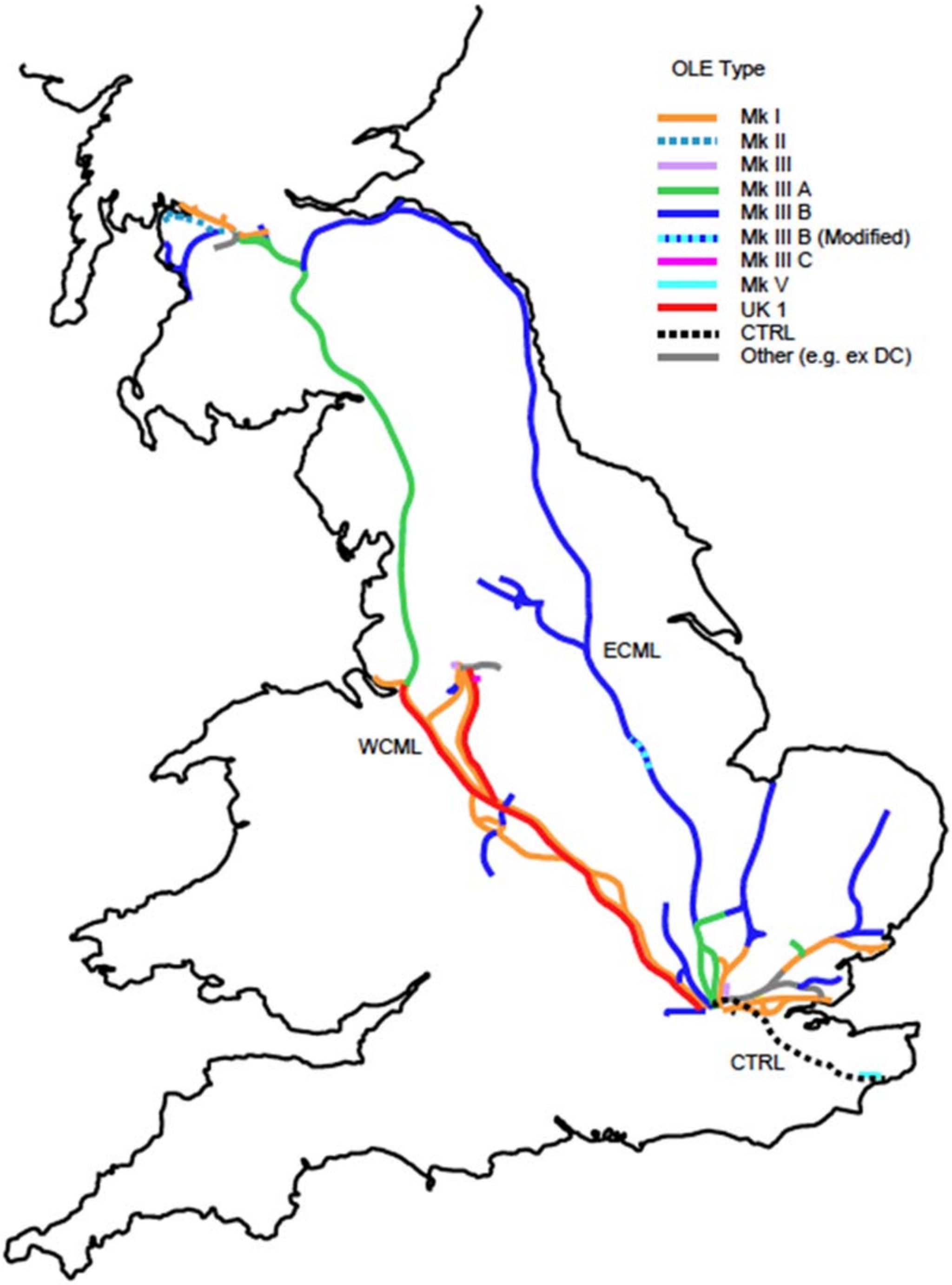


Figure 4 - OLE by route - sourced from RSSB summary report for T346.

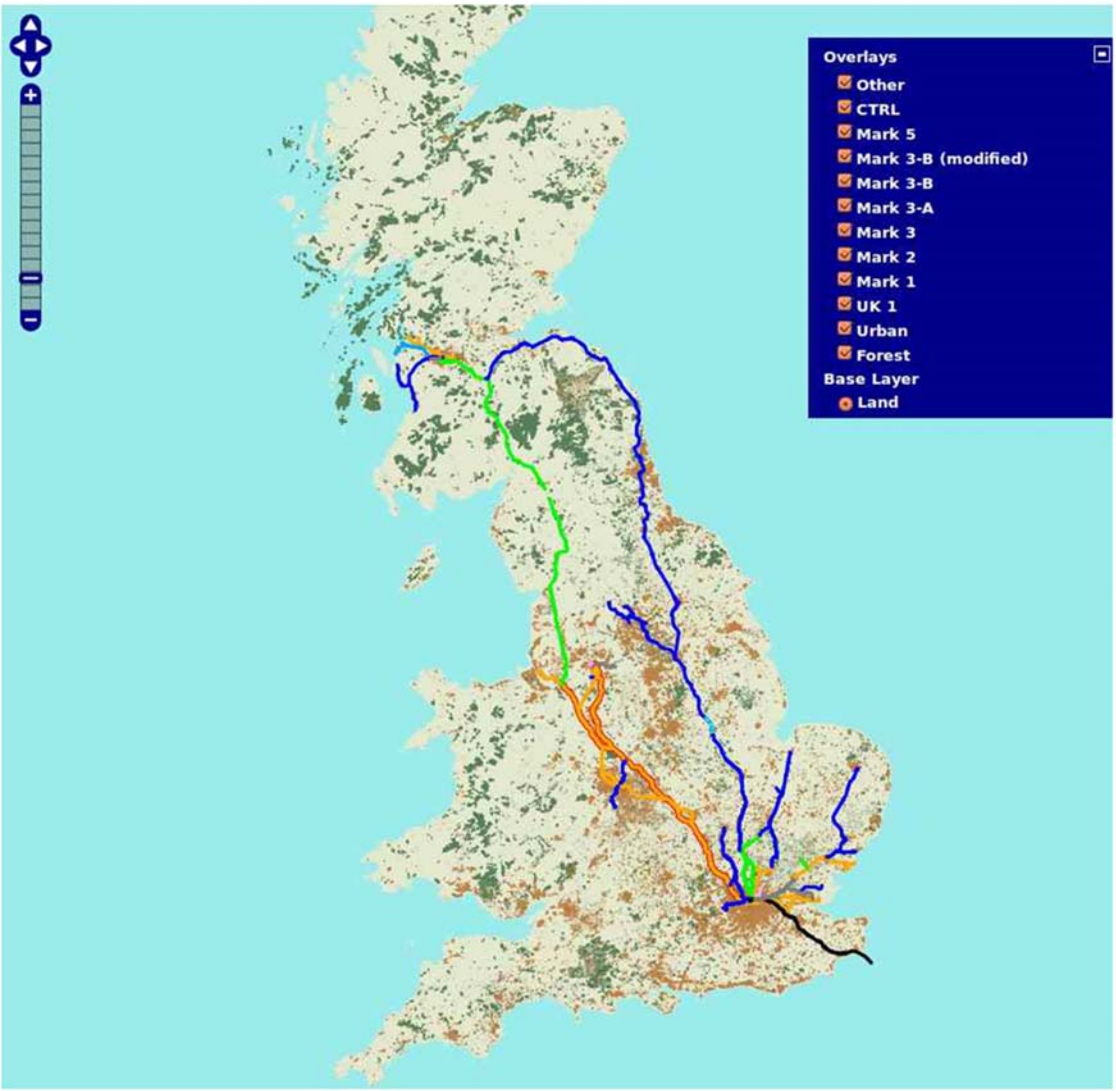


Figure 5 - Screenshot of the interactive OLE map produced by the project team.

OLE issues on the Anglia route and LNE

Wind-speed-based speed restrictions due to OLE are thought to only be a significant issue in Anglia, where a combination of movements in a small number of the support structures and track movement has resulted in the OLE equipment being slightly out of position relative to the vehicles, and the extreme northern end of LNE, where incorrect design (overly long span lengths) means it is unable to cope with the wind speeds locally.

Different OLE structures have different maximum span lengths, although not all spans are of the maximum length as other infrastructure elements (such as: bridges, curves, switches and crossings) often enforce placement locations or result in the need for additional supports. Worst case expected crosswinds for the area are also taken into account during the design process, lowering the maximum span length if appropriate. At the northern end of the LNE route where the installed structures are Mk3b, the span length will never exceed 73 metres although this has caused some difficulties with dewirement and additional support structures are planned. In more modern catenary designs the max span length has been reduced by 15% to 20%, to around 65m, meaning that blow off should not occur in these installations.

The influence of observation height on wind speed thresholds

A key question that arose as a result of the project team's interviews with route control staff was why the wind speed threshold limits used with live anemometer data (around 45 miles per hour) appeared to be significantly different from the standard threshold limit applied to the national weather forecasts (60 miles per hour). The answer to this lies in the height difference between the national standard for wind speed observations and predictions, which are based on a 10-metre high measurement point, and the height at which trackside measurements might be taken.

The equation below is used to convert between wind speeds measured at different heights over a given terrain type. In the equation, the term $u(z_1)$ refers to the wind velocity at height z_1, $u(z_2)$ to the wind velocity at height z_2, and z_0 to the roughness length of the terrain (approximately 0.03 for open grassland). By applying the equation, it can be shown that a wind speed of 45 miles per hour recorded at a height of three metres is equivalent to a measurement of 56.76 miles per hour at the standard 10-metre height used by the national forecasts; this corresponds well to the 60 miles per hour threshold applied to the same national forecast data.

$$\frac{u(z_1)}{u(z_2)} = \frac{\log_e\left(\frac{z_1}{z_0}\right)}{\log_e\left(\frac{z_2}{z_0}\right)}$$

The proportion of the railway present in urban and rural environments

In light of the evidence stating that the blanket 50 miles per hour speed restrictions are more likely related to the increased risk of debris on track than they are to the risk of dewirement, the project team have compiled Figure 6. The figure shows a map of the UK with woodland highlighted in dark green and urban areas shown in brown. The remainder of the area can be assumed to be rural. Overlaid on the map is the UK railway network (shown in black) and from this it is obvious that a large proportion of the network, perhaps as much as 50%, does not fall in an area where substantial blown debris (shed roofs, plastic sheeting, tree branches etc.) are likely to occur. In these areas in may be possible to develop a safety case to allow a higher speed restriction in the event of high winds.

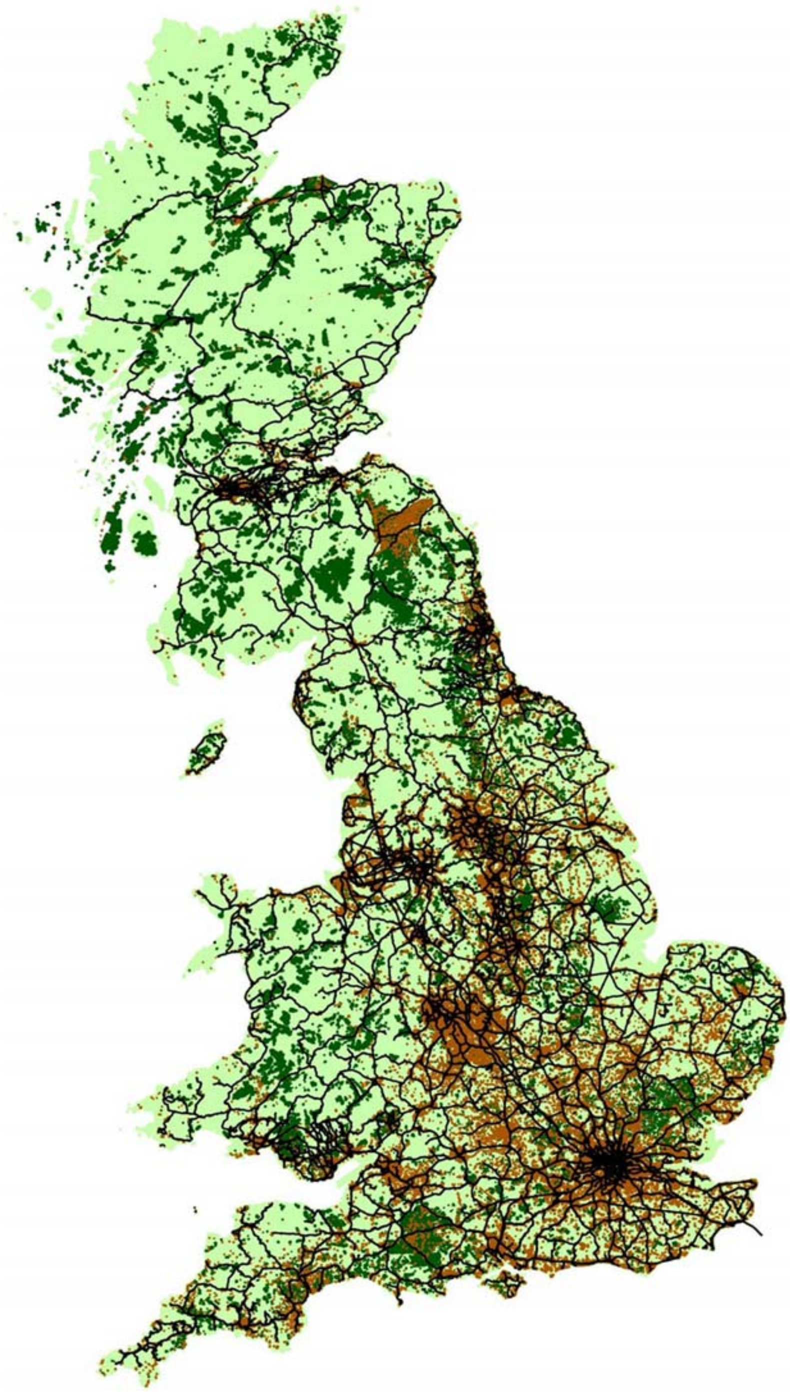


Figure 6 - Map of the UK showing areas of woodland (dark green) and urban (brown) terrain, overlaid with the UK railway network.

Usage of wind speed measurements to generate alerts by the Highways Agency

In many respects the problems due to high winds faced by the Highways Agency are similar to those on the rail network, with major roads and railways often running in close proximity to each other and both transport modes featuring comparably high-sided vehicles that make use of exposed structures such as bridges / viaducts by necessity. During the interviews with route control staff, the idea of sharing wind speed alerts, along with other meteorological information, with the Highways Agency was frequently mentioned and it makes sense therefore to include a brief discussion of the wind speed alert process used on the roads as part of this work.

A summary of the Highways Agency's guidance to its operators is shown in Table 3. Although there are obvious differences in the wind speed thresholds used in the two domains (rail vehicles are after all a guided transport mode and therefore less susceptible to movement by low wind speeds than articulated lorries, caravans or other similar high-sided road vehicles) several other comparisons can be made between the two.

While the rail industry imposes a single blanket speed of 50 miles per hour in response to high wind speeds, the highways have chosen to implement a variable scale of restrictions. Although differences in both the rationale behind the restrictions (vehicle movement on the highways vs. a combination of debris on track and, arguably, OLE blow off on the railways) and the mechanism of information delivery (matrix signs on the roadside vs. the various methods for the railway discussed earlier) do exist, the variable speed limit model used by the Highways Agency could be of value to the railways. The potential benefits of a shift to a variable speed limit model include an overall reduction in accrued delay minutes, and the introduction of this type of model was one of the improvements to the existing arrangements suggested by the route control team on LNE during the stakeholder interviews.

Two key requirements would need to be met before the introduction of a variable speed limit system could be seriously considered; a reliable mechanism for the delivery of the speed limit information to drivers would need to be devised and a safety case would need to be made for the speed thresholds to be used.

From the perspective of information delivery, the rollout of GSM-R appears to offer a significant opportunity for greater granularity to be introduced to the limits on the railways, with drivers being notified at the start of their shift of an expected speed restriction in the area (as is the current case) and the GSM-R system delivering the precise speed limit on approach. It is unclear however, whether the coverage of GSM-R would be sufficient to guarantee that the speed restriction messages would be delivered to drivers everywhere on the network.

Establishing the safety case for changing the speed restriction thresholds would undoubtedly be even more complex, and would need to be proceeded by the formal establishment of precisely why the current restrictions are in place; be that because of (as originally believed by the team at the start of this project) OLE blow off, or because of an increased risk of debris on track as the stakeholder interviews conducted for this work have strongly suggested. Assuming that the current processes are proved to be a response to track debris, in all likelihood the argument for more granular limits would need to be based on the use of the existing 50 miles per hour restriction for very high gust speeds (around 80 miles per hour) with lesser restrictions at lower gust speeds based on a combination of line of sight distances and vehicle braking characteristics.

The other major comparison to be made between the railways and the Highways Agency advice on wind speeds, is that the Highways Agency has a clear procedure for the removal of restrictions as a response to changes in the live data, with a requirement for wind speed to have been shown to have dropped below threshold for a period of 15 minutes before the restriction can be stepped down to the next level.

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Table 3 - Summary of wind speed alert advice to Highways Agency operators

Process step	Details
1	Establish that wind speeds are high via Met Office reports or anemometer readings.
2	Decide on the variable message signs (VMS) to be set using the steps below.
3	If gust speeds are between 30-34 miles per hour for 10 minutes, monitor CCTV to ascertain if high winds are affecting drivers' ability to handle vehicles. Request Highways Agency Traffic Officer (HATO) patrols observe vehicle behaviour and identify locations where vehicles appear to have difficulties. If drivers are experiencing difficulties, appropriate VMS should be activated to provide warning of high winds.
4	If gust speeds are between 35-39 miles per hour for 10 minutes, set VMS to provide warning of high winds. Speed advisory of 50 miles per hour to be indicated on motorway sections.
5	If gust speeds are between 40-44 miles per hour for 10 minutes, set VMS to provide warning of high winds. Speed advisory of 40 miles per hour to be indicated on motorway sections. National Traffic Control Centre (NTCC) to inform appropriate media of high winds including advice to drivers of high-sided vehicles to consider alternative routes.
6	If gust speeds are between 45-49 miles per hour for 10 minutes, set VMS to provide warning of high winds. Speed advisory of 30 miles per hour to be indicated on motorway sections. NTCC to inform media of high winds including advice to drivers of high-sided vehicles that severe danger exists and they should leave or not use the motorway.
7	If gust speeds are between 50-54 miles per hour for 10 minutes, set VMS to provide warning of high winds. Speed advisory of 20 miles per hour to be indicated on motorway sections. NTCC to inform media of high winds including advice to drivers of high-sided vehicles that severe danger exists and they should leave or not use the motorway.
8	If gust speeds are 55 miles per hour or above, serious consideration to be given to the closing of the motorway section affected by high winds. NTCC to advise media of closures.
9	Monitor conditions through anemometer readings and monitoring of traffic. If wind gust speeds are increasing go to 2, else go to 10.
10	If gust speed remains below critical operating level of advisory speed displayed for a period of 15 minutes, and in absence of further information from Met Office, restrictions to be eased in reverse order according to wind speed banding. If gust speed of 35 miles per hour has been recorded for the last 15 minutes, go to 12. If gust speed of 30 to 34 miles per hour has been recorded for 15 minutes, go to 11.

Table 3 - Summary of wind speed alert advice to Highways Agency operators

Process step	Details
11	If gust speed decreases to 30-34 miles per hour for 15 minutes, remove advisory speed signals leaving other advisory VMS activated, go to 3.
12	If gust speed decreases to less than 30 miles per hour for 15 minutes, remove signals.

Approaches to wind speed forecasting

Several potential approaches to near term wind speed forecasting have been identified from the rail industry and other sectors. The approaches vary in terms of the nature of the wind variable forecast (mean wind speed, gust speed), the forecast horizon and whether they treat the station data in isolation or make use of synoptic forecasts from meteorological service providers downscaled to a local level.

Time series analysis

The forecasting approach used by Huang and Chalabi (1995) was developed for controlling the internal environment of green houses. Heat is lost during periods of high winds, so the desired control system would use short-term wind forecasts to automatically adjust temperatures to account for this loss and maintain the internal temperature.

A time series of around 2000 hourly Met Office wind speed observations were used to build the forecasting model. The forecasting model effectively fits a curve through existing weather station data, and predicts the future wind conditions on a one hourly time step. As wind is speed is a non-stationary process, a time varying autoregressive (AR) process is used, with the preceding two hour's mean wind speed measurements used to predict the mean wind speed of the following hour. The R^2 values of the forecasts reduce as the time horizon increases, but it appears to be fairly effective for nowcasting 2-3 hours ahead. However, it must be noted that this approach is concerned with mean wind speed and not gust speed.

The main benefit of this approach is that it can be implemented in isolation and without input from large-scale meteorological forecasts. Hence, it would be suitable for an automated wind alert system and would require little interpretation. Although this approach is based on hourly time steps, it could be implemented at shorter time scales. The algorithms are available and could be applied to the locations easily, although this approach would require considerable calibration using the wind data from the stations.

The main caveat is that it is based on mean wind speeds rather gust velocities and as such is not ideal for many of the railway asset classes in question. It is possible that a simple coefficient could be applied that would give an indication of the potential gust speed based on the mean wind speed. Furthermore, this approach does not take wind direction into account, which again, is important for several wind alert applications. This could be taken into account in the wind alert algorithm, either persistence (this hour's wind direction will continue into next hour), interpretation/integration of other weather forecasts supplied to Network Rail, or through additional forecasting algorithms from the relevant literature. Additionally, the wind forecast is for the site in question alone – any variations in exposure and topography along the line are not taken into account, so would require interpretation based on local knowledge or integration with an interpolation model that would take into account terrain. Finally, as the forecast is driven purely by the statistical analysis of data from the site in question, the model is incapable of predicting the sudden changes in wind speed that would be witnessed as a front passed over. The prediction of sudden changes of this type is the sort that would require the input of synoptic scale forecasts and may therefore be beyond the scope of the system without additional inputs from the national forecast provider.

Downscaling forecasts to the local level

This model was developed by Landberg (1999) for the predicting the power output of wind farms and uses a range of meteorological models at different scales. This approach assumes the cooperation with meteorological service providers to provide the large-scale overview meteorological forecast. These large-scale numerical weather forecasts are used to produce the geostrophic wind (the wind at around 1000 metres, which flows parallel with the isobars), which is then transferred to the surface using the geostrophic drag law, changing both the speed and direction to account for surface friction. Empirical local models that take into account topography are then used to forecast the wind at the location specific location in question.

The model has a timescale of the order of a few hours and is in effect the equivalent of a localised weather forecast. The approach is inherently better suited for longer time periods than statistical time series analysis, and begins to outperform persistence at around 6 hours ahead. It has the benefit of taking the large-scale meteorological situation into account. For instance, purely statistical techniques would not take into account sudden changes in wind speed brought about by a front passing over, but would be captured by the dynamic forecasting techniques provided by the large-scale models. Importantly, this also allows it to forecast wind direction as well as wind speed.

However, this approach is again concerned with average wind speeds, which may not be suitable for many of the intended applications at Network Rail. This approach is also far more reliant on cooperation with meteorological service providers in the supply of the large scale and synoptic forecasts. The forecasts would again only be applicable to the site of the meteorological station, so would require interpretation for anywhere else on the line.

Statistical nowcasting of gust speeds

This approach was developed by Hoppmann et al. (2002) for Deutsche Bahn. It is concerned with short-term prediction of gust speeds as an input to a wind alert system to reduce the risk of crosswinds on high-speed rail lines. The forecasted gust speeds are used to impose speed restrictions specific to the particular category of train in question. The project has parallels with the Network Rail approach, with anemometers being position at eight locations along the railway track. The spacing of the anemometers along the track was not homogeneous, and was instead dictated by the relative risk of wind gust (they were positioned on bridges and at curved sections on banks). The specification of the system was to predict as least 97.5% of strong gusts above 20m/s experienced at the site of each anemometer, with a lead-time of 120 seconds (DB has an in-cab signalling system that can be used to alert drivers to the current line speed). The approach of the gust prediction model is:

1. The 10-minute wind speed averages of the previous 30 minutes are linearly extrapolated to estimate the average wind speed 2 minutes into the future.
2. An error supplement is added to the extrapolate average wind speed (determined during calibration).
3. The 10-minute standard deviations of wind speed over the previous 30 minutes are extrapolated 2 minutes into the future.
4. A gust supplement is calculated using factors determined during calibration. From this maximum expected wind speed during the next 120 seconds can be forecast.

This approach would be fairly simple to implement, but requires extensive calibration, ideally with a two year dataset being used. This is the only identified approach that forecasts gust speed and has obvious relevance to this project. However, the short time scale of 120 seconds may need to be discussed, as certain applications will probably require a greater degree of warning. The authors also looked at the benefit of adding wind direction to the prediction model, which was found to lead to a small reduction in wind warnings (around 5%) but a large increase in the complexity of the model. This is a statistical approach based on data from a single location, so would not be able to take the wider meteorological situation into account. An examination of spatial transferability was made and found that the probability that an observed wind speed will be recorded at another site during the following 10 minutes reduces to less than 40% at distances greater than a few hundred metres. This distance relates to the average extent of a gust, and means that the nowcast can only be accurately relied on for the immediate surrounding area of the station, hence station positioning is of great importance.

Potential implementation

For our purposes it would thus seem that the DB model is of most direct relevance, as it deals with gusts rather than mean values. The approach seems to be quite straightforward and could be implemented in isolation for each station without reliance on external meteorological input. However, it is possible to see how a combination of all three approaches could be used to improve forecast performance at all levels. In addition to accurate near term gust speed prediction, average wind speed up to two to three hours ahead could be forecast using the time series analysis approach. An indication of likely wind speeds may also be possible at this time horizon using a simple coefficient based on the observed statistical relationship between average and gust speeds. Finally, depending on the type of forecasts provided to Network Rail, it may be possible to downscale large-scale numerical weather forecasts to the local scale to provide more accurate wind forecasts at time horizons from several hours to days. At this level the primary purpose of the station data would be to calibrate the forecast derived from the physical and statistical models.

External data sources with the potential to contribute to a wind speed alert system

In addition to data from the weather station network, a number of other information sources are available that can provide both live observation data for key climate variables and national weather forecast information. While perhaps not hugely useful as additional sources of information for wind (which is subject to localised variations in its effects), some of these sources could provide useful information on rainfall levels at sites further away from the railway and therefore are noteworthy in the wider context of the project.

Met Office

As the UK's national weather forecasting service, the Met Office has a network of around 270 automated synoptic weather stations in place around the country. Additional wind only and manual reporting stations support this network. The complete station network is shown in Figure 7 (red = manual station, blue = automatic station, turquoise = wind only station, sourced from [4]). Live data streams from the Met Office can be accessed via the DataPoint service (http://www.metoffice.gov.uk/datapoint) and includes live observations from around the country, hourly forecasts for around 5000 grid locations and synoptic charts.

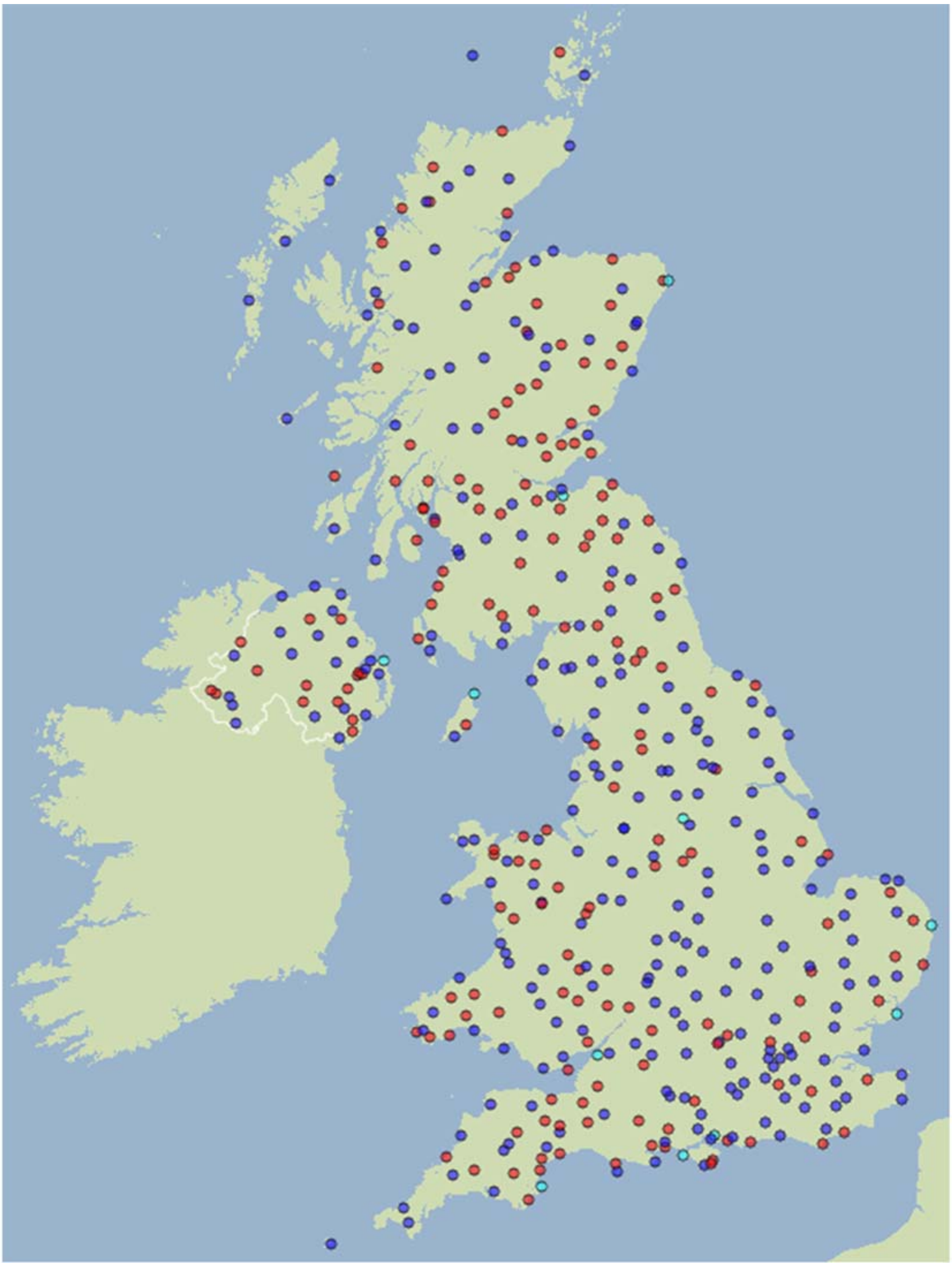

Figure 7 - The Met Office's national weather station network. Sourced from [4].

Live observation data coverage of the railways by Met Office national weather station network

While the network of weather stations used by the Met Office includes around 270 automated synoptic sites, only 122 of those locations are currently streaming observation data via the DataPoint service (providing hourly observation data via a public API that could currently be used to inform the wind speed alert process).

Figure 8 has been created by the project team and shows the DataPoint enabled weather stations overlaid on a map of the UK rail network obtained from OpenStreetMap. At the scale of the diagram, red markers (which are centred on the weather station locations) cover a radius of around two miles / diameter of around four miles on the ground; this is more than sufficient distance for natural geographical features, along with railway structures such as cuttings and embankments to begin to impact on the wind speed and direction that would be experienced trackside when compared with the observed wind speed at the weather station.

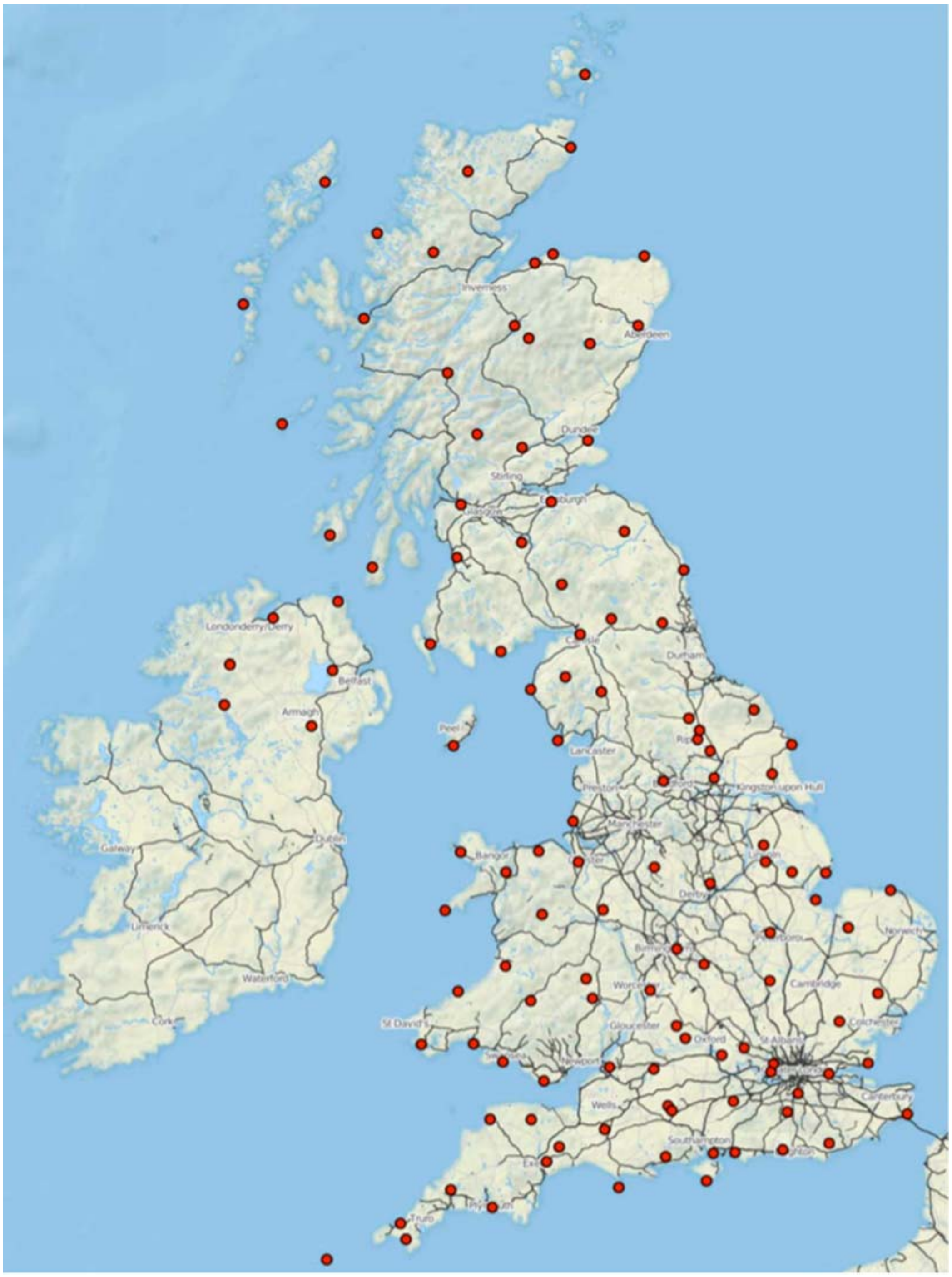

Figure 8 - Location of Met Office DataPoint stations overlaid on the rail network.

National forecast data

Complementing the live observation feeds, DataPoint also provides access to a range of national forecast products. These include 3-hourly site forecasts running to a 5-day horizon for over 5000 sites in the UK. Forecast streams contain information on wind speed (average and gust) and direction, temperature, precipitation and visibility. As with other DataPoint products forecasts are made available as XML and JSON feeds. The national coverage of weather forecast products is significantly better than with the live observation data, and therefore it has potential to act as a valuable supplementary information source to the national weather station network that Network Rail is planning to install, although given the comparatively low update frequency it may only be sufficient to predict the likely imposition and removal times of restrictions as opposed to actually being used to deliver them.

Synoptic charts

Synoptic or surface pressure charts are used in a wide range of weather forecasting tasks. The Met Office DataPoint service can be used to access surface pressure charts out to a 5-day horizon (see Figure 9 for an example chart from the service), although they are only available with a resolution of 12 hours for days 1-3 and a resolution of 24 hours for days 4 and 5.

While the URLs that allow the charts to be downloaded can be accessed via the usual XML and JSON feeds, the charts themselves are only available as images and therefore would be difficult to integrate into an automated wind speed alert system (although they would arguably be of use to route control staff as part of a wider weather portal product given appropriate guidance on usage).

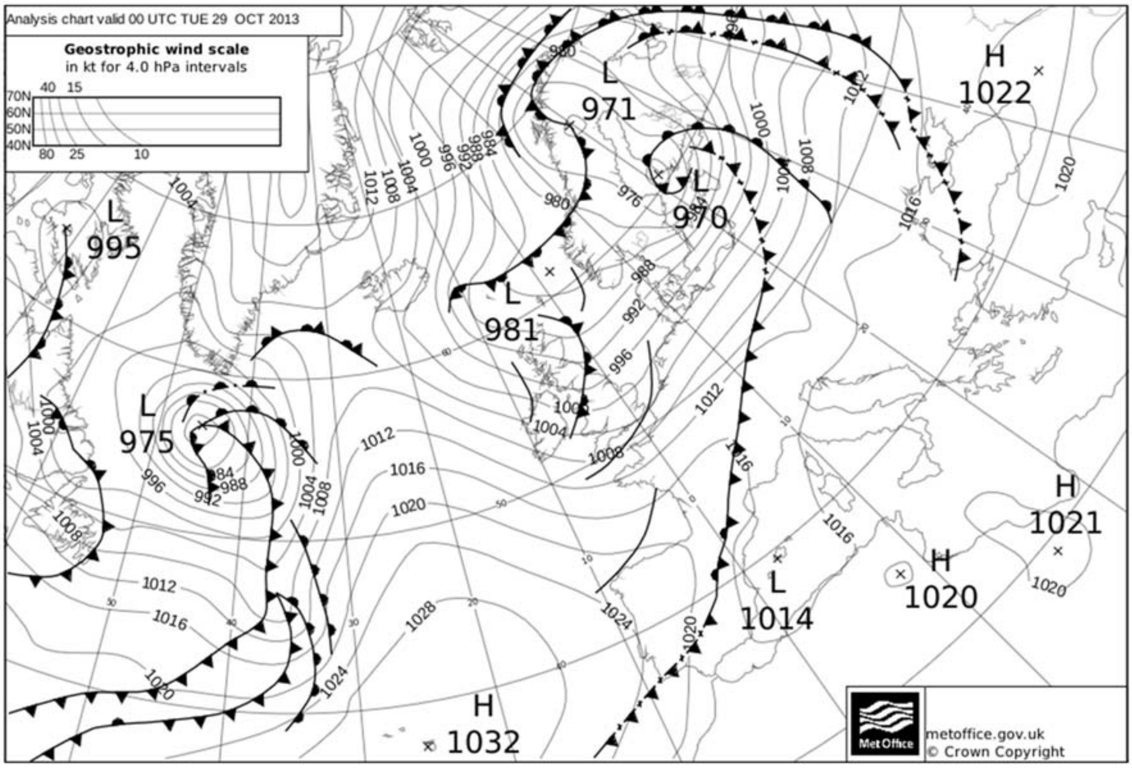

Figure 9 - An example of a synoptic chart as available via the Met Office DataPoint system.

Weather underground

Weather Underground (http://www.wunderground.com) is a web site providing access to a network of over 36,000 privately owned weather stations operated by amateur meteorologists around the world. The locations of UK based stations in the network can be seen in Figure 10. The network provides access to a wide range of data feeds, although for anything other than a limited number of access attempts a day (500 attempts a day at time of writing), these are charged for according to a usage based sliding scale.

Data streams available from Weather Underground include live observations, 10-day, 3-day and hourly forecasts, and satellite and weather radar images, as well as historical observations gathered over the last 25 years. As with the Met Office DataPoint service, streams are provided in XML and JSON and accessed using an individually assigned key.

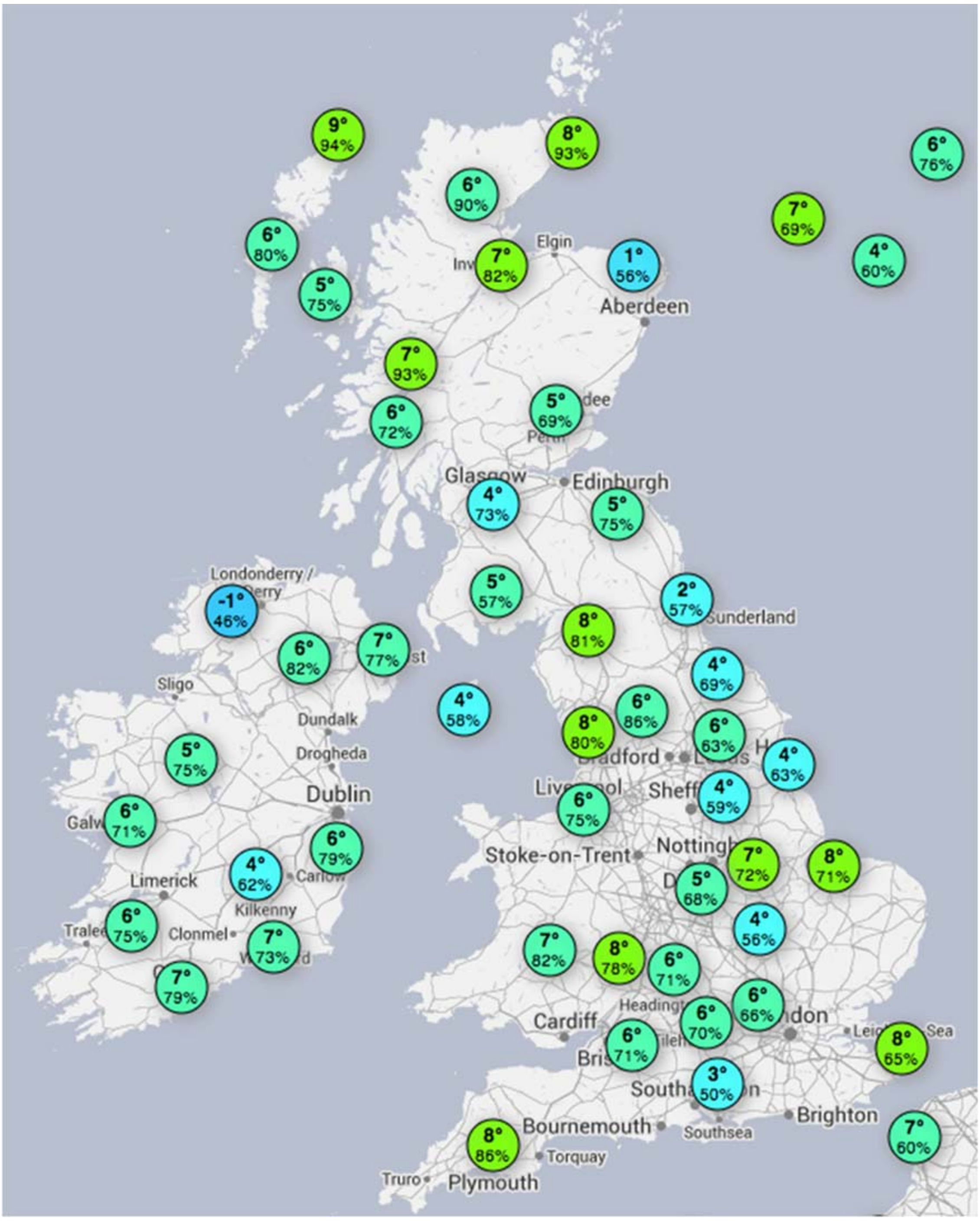

Figure 10 - UK weather stations available via Weather Underground.

Industry information systems

Amongst the plethora of industry information systems used by the UK railways, a number have been identified (see [5]) that could act as potential consumers of information from a wind speed alert system (such as advising passengers of expected delays). These include:

- LICC - Provides real time customer information to passenger information systems.
- TIGER - Provides customer information over the Internet.

Potential operational uses and distribution mechanisms for wind speed data

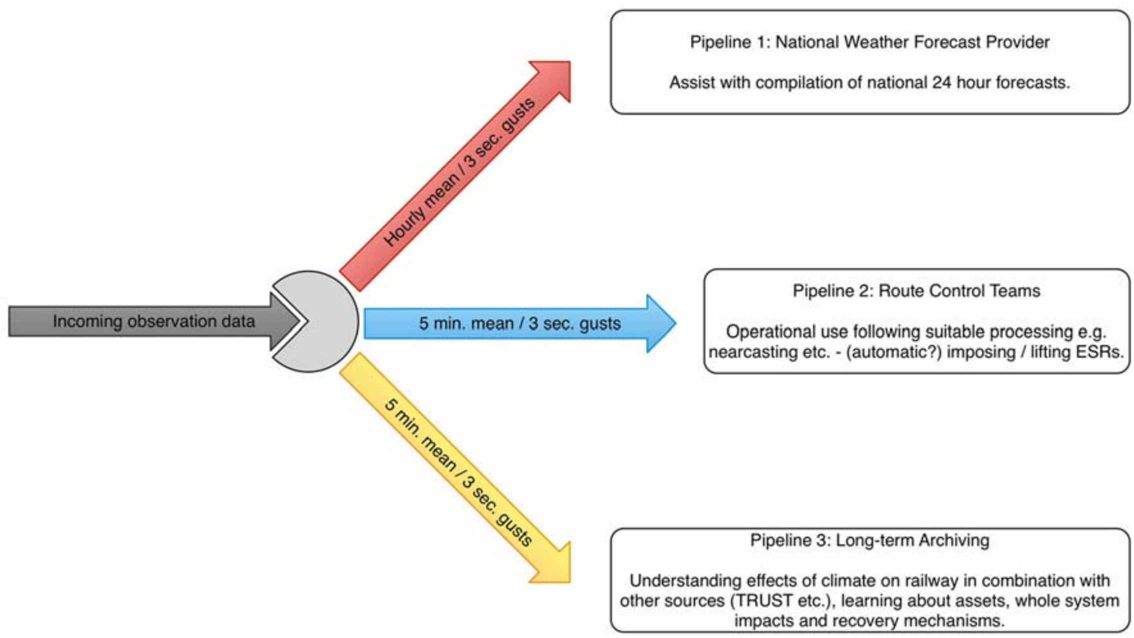

Figure 11 - Potential usage channels for live wind speed information.

The project team envisage a future system in which recorded wind speeds (and ideally information on the other climate variables being monitored by the new weather station network) is handled in three different processing pipelines as shown in Figure 11.

In pipeline 1, hourly mean and 3-second gust wind speeds will be made available to the national forecast provider to assist them in the preparation of their forecast products. This has an obvious benefit for the industry and would incur very limited (if any) additional cost for Network Rail, although the project team recognises that commercial arrangements and/or remuneration may need to be agreed for this to be practical. An XML interface very similar to the STOMP-based system used to publish TRUST data to developers would be an ideal architecture for this system.

Pipeline 2 would feed information to the route control teams, providing climate data for operational usage. In the case of wind speeds, this data would be sampled on a 5-minute mean and 3-

second gust basis, and would be used in both live (direct comparison against the known triggers and thresholds for alerts) and pseudo live (generation of nowcast predictions for the next 2-3 hours) contexts. Further information on the usage of the information, system requirements and suggested interface screens for route control team members are discussed in the following sections.

Pipeline 3 will be used for long term archival of the recorded data beyond Network Rail's own operational and auditing needs. Wind speed data would be supplied on a 5-minute mean and 3-second gust basis (as with the operational data in pipeline 2) and ideally should be made available via an XML gateway to a public repository, allowing maximum benefit to researchers. Data archived in this way could deliver substantial benefits to the industry in the long term, through both an improved understanding of the changing climate and analysis of the whole system impacts of extreme climate events on the railway (for example through its combination with public information from TRUST that is already provided by Network Rail). The British Atmospheric Data Centre would be a good candidate organisation to host this information, or alternatively hosting could be agreed with a research institute or University in exchange for an agreement it could be used as the basis of publications.

A potential evolution of the wind speed alerts process to 2025

In order to place the wind speed alert system in an operational context, the project team was asked by the steering board to provide diagrams showing how the current process (as used by the routes, rather than as strictly stated in the standards) might evolve over the short to medium term thanks to the provision of real time wind speed alerts.

Figure 12 shows the process of imposing and removing blanket speed restrictions in response to high winds as it currently stands (this is the same process discussed in the section of the document relating to the route control team interviews). The green box at the top left of the figure is an entry point, in this case the delivery of the national forecast to the route control team at around 03:30 each morning. The two boxes that are shaded red represent processes that will eventually be the exit points, albeit after a day's operations are completed. The blue shaded box and the decision point that immediately follows it represent an operator interpretation of the values being seen in live wind speed data; it should be noted that this sequence does not exist on all routes currently using live data, with Anglia responding immediately to alerts raised by RailMet without further interpretation, however, interpretation of live data by the route control teams is still widespread on other routes and it seemed therefore appropriate to include it in the "current state".

A key feature of the diagram is that significant complexity seems to exist in what, on the face of it, should be a comparably simple process (and indeed is based purely on the standards). Much of this complexity is due to the variation in the use of wind speed data around the country, with LNW taking a largely forecast based approach to alerts and Anglia focussing almost exclusively on what they observe in the live data.

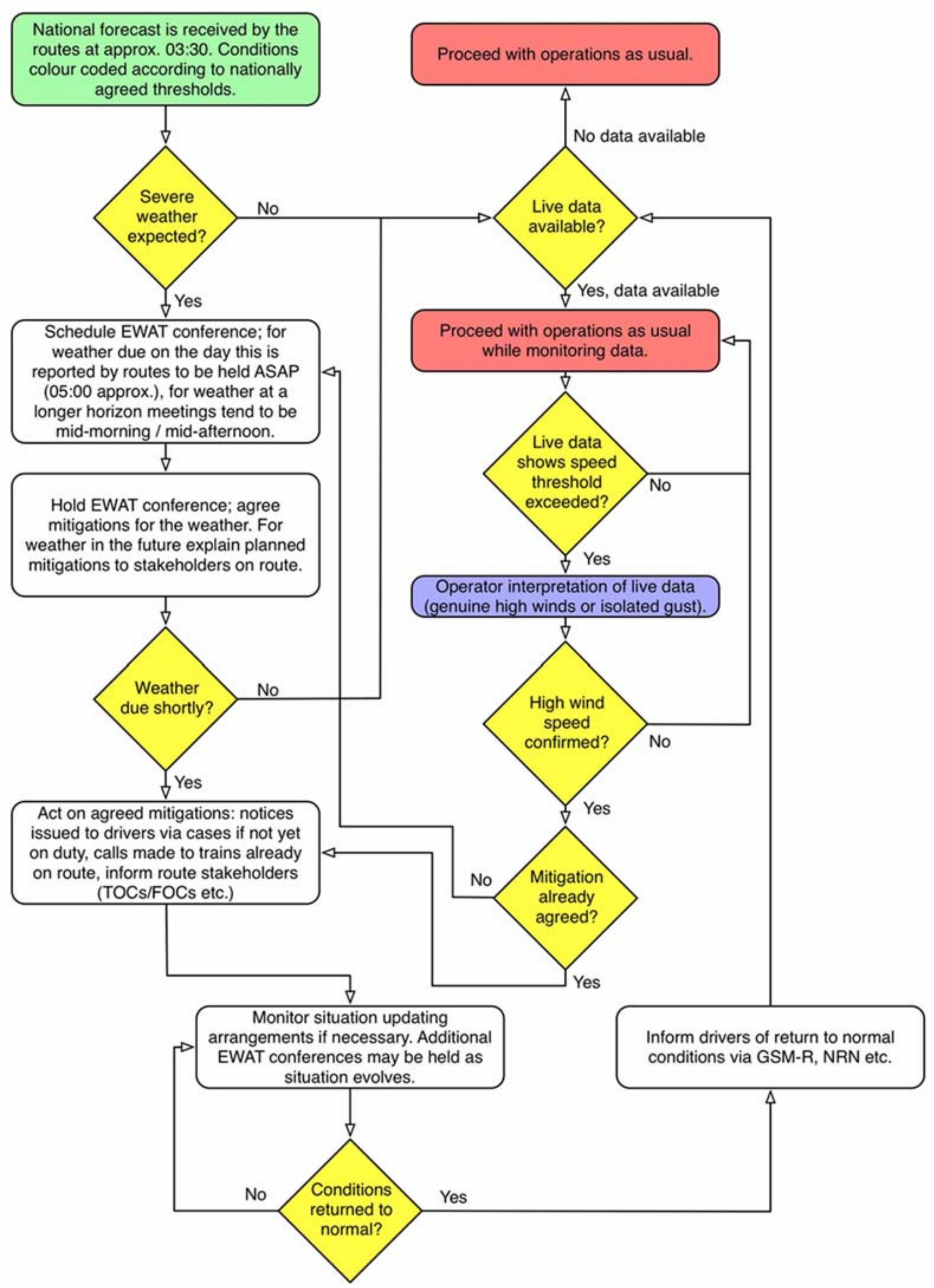

Figure 12 - Wind speed alert process (2013).

Figure 13 shows the authors’ view of the process as it might look in around 2018, following the implementation of the weather station network and assuming the provision of live wind speed data on all routes. The national forecast, received on a daily basis at 03:30, is still a key element of the process allowing planning for extreme wind speeds to take place and route stakeholders to be notified; however, all mitigation actions are now held until the expected weather is observed in the live data. Specific speed limits are now being delivered to the drivers on approach via GSM-R or ETCS signalling, allowing for shorter speed restriction zones (the drivers no longer need to remember the start / end points) and the possibility of multiple speed thresholds if the safety case can be made; however the continued use of the national forecast still allows for advanced notifications to drivers during this “transitional” period. There is no longer an element of operator interpretation of the data in the loop, with mitigations being triggered directly in response to alerts raised by the system, although the route control team still have flexibility in the choice of wind speed alert thresholds at each location, allowing the system to be tuned if needed due to the effects of the local geography or prevailing wind. Nearcast algorithms are used to predict when conditions will ease to assist with planning for the recovery of services to timetable. Overall, the process displays a significant degree of simplification relative to the current practices thanks to the adoption of a unified approach around the rail network.

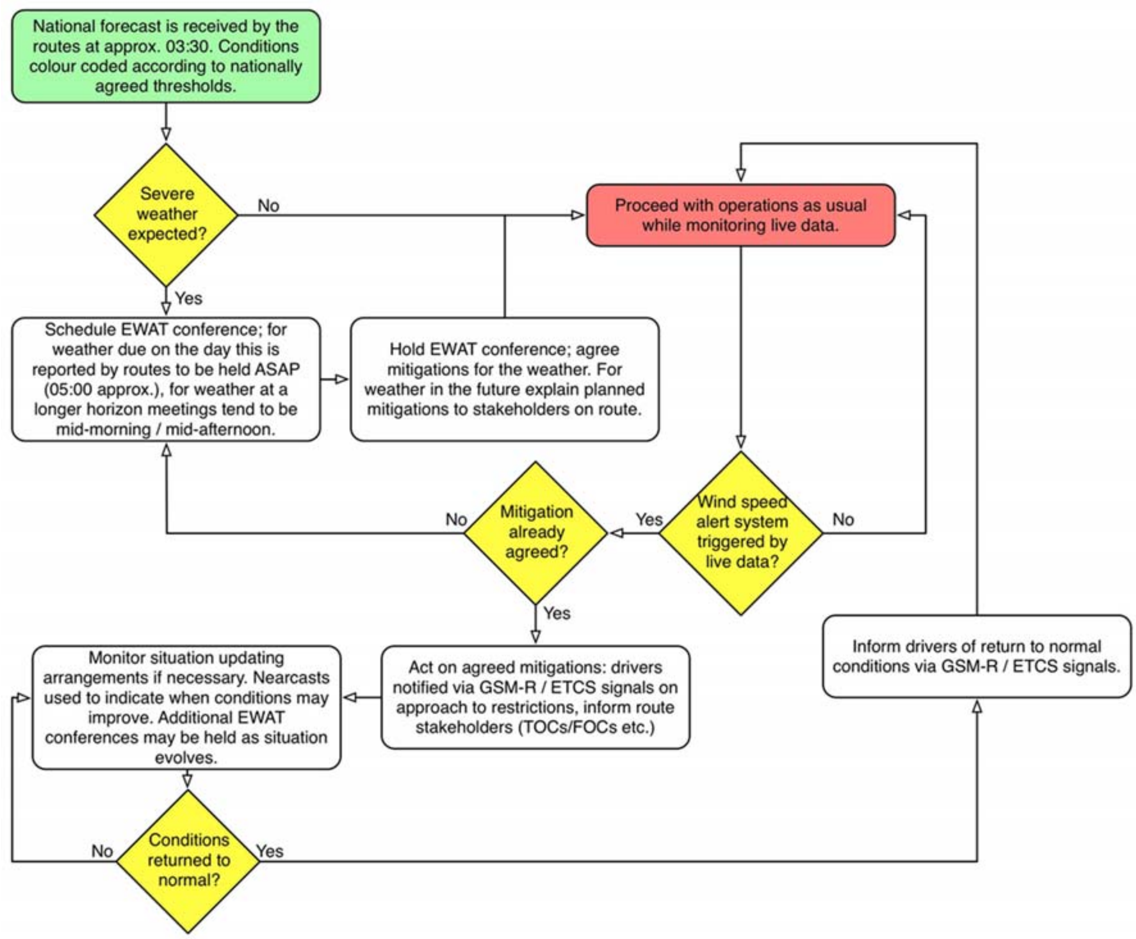

Figure 13 - Wind speed alert process as it may look in 2018.

Figure 14 shows a view of the process into the medium term, in this case around 2025. The process seen here is radically different to the current state of affairs, as the move towards a 24/7 railway, coupled with the availability of reliable, computer derived forecasts out to five days updated on an hourly basis have made the concept of a “daily” national forecast redundant. Route teams still monitor the forecast, however this is now purely to allow notification of maintenance teams etc. in advance of potential bad conditions. Restrictions are imposed solely in response to alerts from the live data. Wind speed alerts are fed into the service bus of the traffic management system, which automatically updates the ETCS signalling system with the speed restrictions, notifies operators and employs novel algorithms (such as those being developed by the EU FP7 ON-TIME project) to adjust rosters for crew and rolling stock dynamically. When the alert system shows the conditions have returned to normal, the speed restrictions in ETCS are lifted, again automatically. The automation of the process, from data to decision and ultimately response, allows a full, auditable trail of actions to be recorded, which can be used for delay attribution.

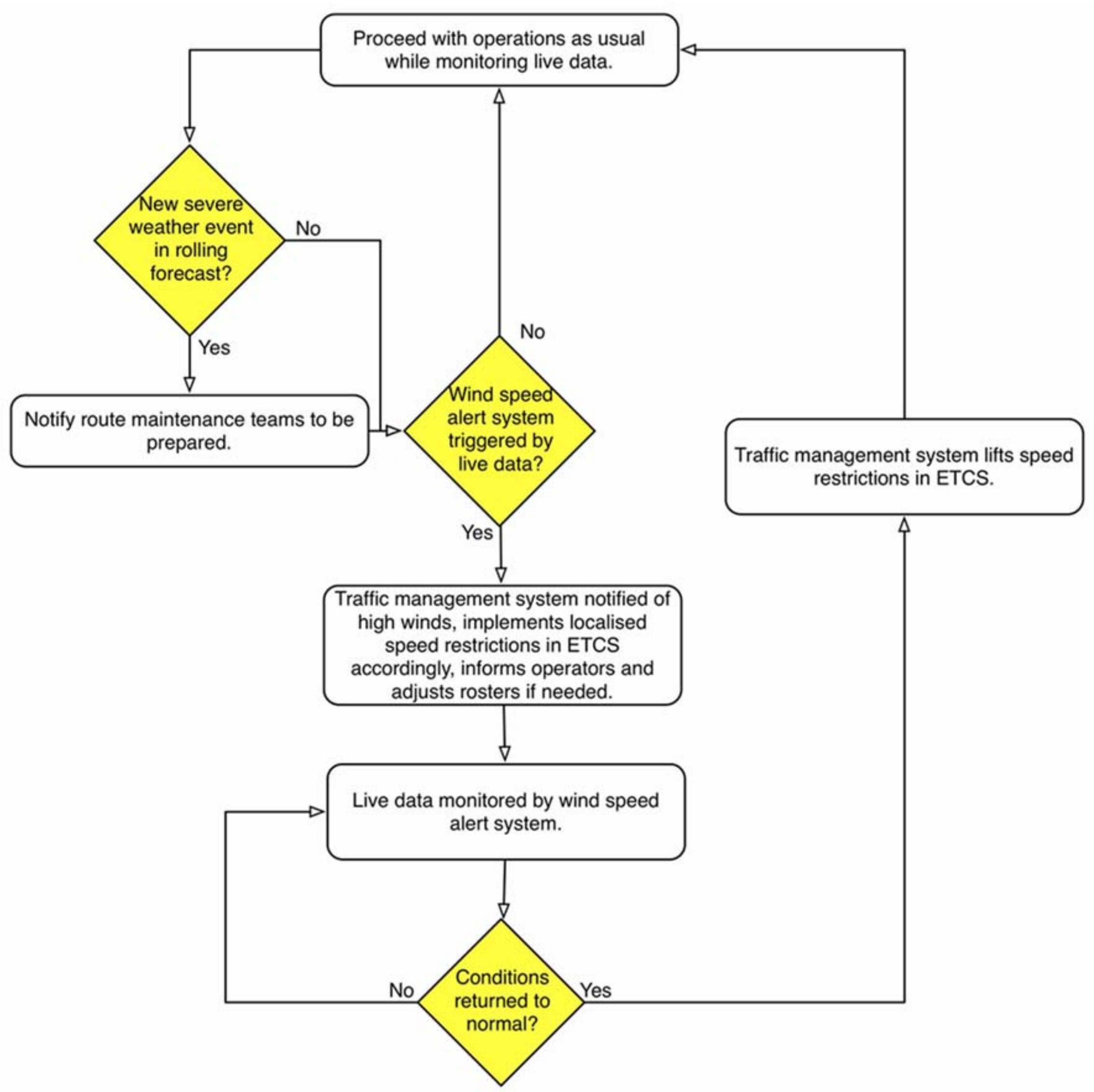

Figure 14 - Wind speed alert process as it may look in 2025.

Requirements for a wind speed alert system

The project team has identified a number of general requirements for a wind speed alert system and they are described in the following sections.

Wind speed samples

Data provided to the wind speed alert system by the Network Rail weather station network should be in the form of the standard 5-minute mean and 3-second gust values. Sampling frequencies at the weather stations should be appropriate for delivery of calculated wind speed information at these frequencies. These data should be provided in as near to real time as practical, although if burst transmission is to be used the data should arrive no later than 15 minutes after recording in order to support the short-term nowcasting process.

Data requirements for prediction algorithms

Time series analysis

If time series analysis of existing data were to be used to predict upcoming average wind speeds, the algorithm would require access to the average wind speed values from the two hours prior to the point of use.

Nowcasting of gusts

If nowcasting of gust speed were to be implemented using the approach discussed in this document, then the algorithm would require access to 10-minute wind speed averages for the 30 minutes prior to the point of use.

Requirements for the suggested imposition and removal of ESRs

Imposition of restrictions

In the absence of further work to provide a safety case for altering speed restriction thresholds to allow for differing debris risks in urban, rural and woodland terrain, the criteria for raising high wind speed alerts from live data should remain as per the current standards process appropriately scaled for weather station height. This means that for a weather station recording at approximately two metres height an alert should be raised and restriction imposed when:

1. The 3-second gust speed values exceed 45 miles per hour once in every 10 minute period over a total of four hours.
2. The 3-second gust speed exceeds 50 miles per hour.
3. Further to the above, services should be suspended if the 3-second gust speed exceeds 65 miles per hour at 2 metre height.

Although high wind speeds alone are not currently thought to be a significant contributing factor to dewirement by the OLE engineer questioned by the project team, they were believed to have an impact in combination with other factors such as vehicle roll, the disturbance of nearby vegetation and movement of structures. For this reason it is vital that route OLE engineers should retain ultimate control over the wind speed thresholds used on their equipment. Any wind speed alerts system developed must, therefore, have the capability for the route OLE engineer to alter the threshold criteria above on a site-by-site basis.

Removal of restrictions

Following the model used by the Highways Agency, suspended services (the result of criteria three above) should be resumed, assuming that other factors are true, such as track is known to be clear, at ESR speed once 15 minutes' of data have shown no gusts over 65 miles per hour.

All alerts and speed restrictions resulting from criteria 1 or 2 above, or from the resumption of services following criteria 3 can be cancelled when 15 minutes of data have shown normal conditions (where 'normal conditions' means that the wind has speeds that will not trigger criteria one, two or three above).

Data auditing and archival

Wind speed data recorded by the system should be uniquely identifiable and held in its entirety by Network Rail for a period of one year. Long-term storage of the complete dataset by an external agency for future research use is also encouraged, as this will provide long-term benefits to the industry for a negligible additional cost. It is strongly suggested that any data that has been the basis for decision making (such as the imposition or removal of an ESR) should be maintained indefinitely by Network Rail, as this would enable its use as a type of audit trail should it be need in the future.

Storage requirements

It is estimated that, on a per station basis, the storage requirement for wind speed data sampled as 5-minute mean and 3-second gust would be in the region of 1MB each year[2]. Assuming a network of 1000 stations, the total data storage requirement for 1 year's data across the network as a whole would be of the order of 1GB.

Interfaces to external systems

Publishing data

In order to support the gathering of data from the network by external parties such as the national forecast provider, the wind speed alert system should be able to publish 3-second gusts, 5-minute mean and 1-hour mean values as XML. In order to be consistent with Network Rail's existing open data feeds (such as the provision of vehicle movement data from TRUST), this should be a STOMP feed.

Alerting operational staff to high wind speed events

Both the Vaisala system in use on LNE and the RailMet system used on Anglia route have features that operational staff can subscribe to in order to receive notifications of high wind speeds on the network, and a key stakeholder request with respect to any future system is that it supports a similar mechanism, either via email or text message. Alert notifications sent from the system should include an element of context; for example, while current alert systems may send a message stating that a threshold has been crossed and a second when the wind speed falls back below the threshold, any new system should include information on the duration of the previous period of high winds and some idea of how that relates to the wind speeds observed during the course of the day: 'The wind speed alert threshold at XX miles per hour has been crossed at location XXXX. This threshold has been exceeded 3 times in the last 4 hours."'

Wind speed alerts as a service

In order to support the potential future integration of the wind speed alert system into a wider core GIS system, software should, wherever practical be decoupled from interfaces and provided as a service. To that end, a standard web service model would be a suitable architecture to adopt for the system.

2 Based on two 32-bit numbers delivered every 5 minutes, 24 hours a day, 365 days a year

Suggested interface screens for a wind speed alert system

As is common in many domains, the generation of timely alert in response to developing events is only useful if that information is presented to staff in a way that is makes it both obvious that important information has been delivered and allows them to interpret the information easily. When asked about how they would like information presented to them during the stakeholder interviews, route control staff all had very similar opinions. Information should be presented as a series of individual screens rather than tabs because it's easy to add monitors but time consuming to keep switching manually between tabs. Wind speed and direction should be shown in relationship to the track orientation in the area because crosswinds may require different responses to headwinds. Wherever possible colour coding should be used to make it easier to identify important information; this would be particularly important if a large number of new weather stations were to be included in the system.

Screen concepts

The draft screen concepts in Figures 15 and 16 are based around the principles developed in conjunction with the route teams. Figure 15 shows a live observations screen. Each site is identified by name, although this could easily also include or be replaced by a track distance or GPS coordinates (indeed the inclusion of location data alongside the site name was one of the improvements suggested by the LNE route team). By selecting a site, the user displays its location on the map. Sites are displayed in track order, although the operator can shuffle the ordering if they want particular groups of stations listed together. For each site, information is displayed on the wind direction, the track orientation, and the latest 5-minute mean and 3-second gust figures. The sites are also colour coded according to the threshold values defined in the national standards (suitably adjusted to allow for the variation in height between trackside equipment and the nominal 10-metre measurement) this allows operators to easily identify sites where action is required.

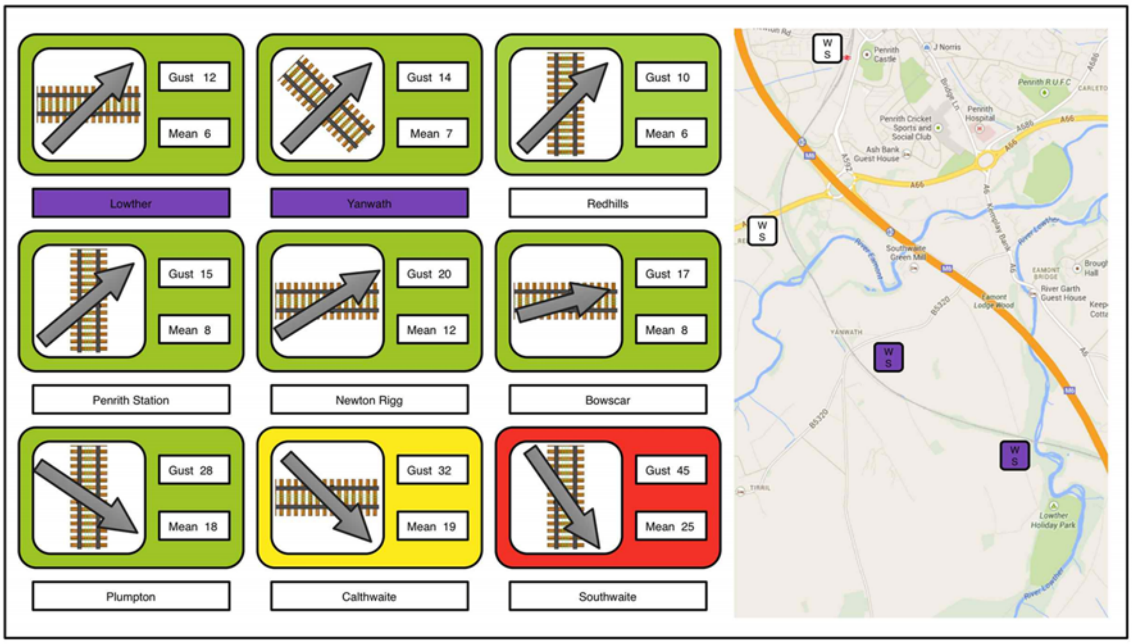

Figure 15 - Concept interface screen for wind speed observation data.

Figure 16 shows a similar concept for forecast information. Here forecast data is displayed as a colour coded matrix of wind speed values, identified by location and time. The user can scroll the matrix to see further into the future, although as an alternative the values could be collapsed or expanded using a similar mechanism to column hiding in spreadsheet applications. In combination with an approach such as nowcasting, this presentation mechanism allows for high resolution sampling in the near future (for example once every 5 minutes predicted using the weather station data out the 2 hours) with the sample rate dropping off in the longer term as forecasts switch to hourly figures from the national provider. Where the wind speed alert system predicts threshold values will be exceeded and ESRs will need to be put in place, the interface boxes the values together in red; the section of track affected is identified on the map, giving route control staff a clear idea of the extent and duration of the disturbance to service.

Figure 16 - Concept interface screen for forecast wind speed data.

Final thoughts and conclusions

Although based on the stakeholder interviews conducted during WP01 of the T1020 project it seems likely that the 50 miles per hour blanket speed restrictions imposed in response to high winds are due to increased risk of debris on the line rather than because of an increased risk of pantograph blow off as thought prior to the project, the concept of using local wind speed information to impose shorter speed restrictions still has value to offer the industry. However, barriers beyond the provision of the wind speed data itself do exist to this change and one particularly important issue revolves around the distribution of much more dynamic speed restriction information to drivers in a reliable manner. While the introduction of ETCS is one solution to this problem in the medium term, in the short term a compromise measure may need to be introduced that uses GSM-R to deliver local restriction information to drivers by preference, but with a fall back position of a traditional ESR between major features such as stations.

Throughout the project, there have been suggestions that, given the 50 miles per hour speed limit appears to be a response to the risk of debris rather than dewirement, surely the limit could be higher in rural areas where there are fewer objects to blow onto the line and longer distances in which the drivers could see them than is practical in urban or woodland environments. While this idea is (at least on the face of it) very sound, further work needs to be done to investigate the safety implications of such a change and what the appropriate speed thresholds would be in the various terrain types. It may also be appropriate to treat high-risk areas differently to the rest of the rail network. Until recently for example, the LNW control room staff reported that it was common practice to only impose speed restrictions due to high winds in very exposed areas, such as Shap Fell.

An idea that was echoed by all the route control teams was that for an automated wind speed alert system to be successfully adopted by industry staff, accuracy of information had to be the key criterion. As the accuracy of the wind speed alert system will depend not only on the quality of the software algorithms used but also on the quality of the wind speed data coming in, it is important that for weather stations where the primary use case is wind speed measurement both proximity to passing rail vehicles and the features in the local terrain are considered when choosing the site.

As traceability of the decision making process becomes an ever more important component of life in the railway industry, maintaining a record of how a decision to impose a speed restriction was reached (and thereby attribute delay minutes correctly) is an important element of the alert system. Key to achieving this is the ability to uniquely identify every item of data coming back from the weather station network and maintaining those data used as the basis for decisions long term. In a fully automated system, this is not a difficult task to achieve and the same is true in a system where every data item is permanently archived; in a system where old data is to be discarded after 12 months however, care will need to be taken to ensure only data that has not been used in decision making is discarded.

The complete dataset generated by the weather station network will be an important research tool long after its direct operational usefulness to Network Rail has ended, allowing a better understanding of the effects of extreme climate events on the railway as a complex system to be developed. The authors of this study are keen therefore, to emphasise the importance of maintaining a copy of the dataset in a public repository for future research use, alongside other Network Rail open data products already being gathered from systems including TRUST.

Recommendations

Although the 50mph blanket speed restrictions used as a response to high winds appear to be due to an increased risk of collision with debris rather than being a mitigation to pantograph blow-off, the ability to impose localised speed restrictions in response to high winds still has value to offer the UK rail industry in terms of reduced delays. With this in mind, the following recommendations are made:

- Work should take place to establish if alternative speed limits in response to high wind speeds could be allowed in areas of the rail network where the risk of debris on track is low. This work should include a comprehensive review of the reasoning behind the current restrictions.
- With the delivery of live wind speed data it should be possible to automate some, if not all, of the wind speed alert process on the understanding that local engineering staff retain ultimate control over the precise triggering conditions used at each site. Work should take place to investigate:
  - Mechanisms by which information on short-term, localised speed restrictions can be delivered to drivers in a reliable yet timely fashion.
  - The feasibility of feeding wind speed alert information directly to traffic management systems thus reducing the need for operator intervention.
  - Mechanisms for the delivery of information on delays due to high winds to passengers, including the expected impacts on their journey and accurate estimates of the extent of the disturbance.
- The data that will be gathered by the weather station network represents a rich source of information that will be invaluable to researchers attempting to understand the whole-system impact of extreme weather events on the UK rail network. Work should be performed to establish how this data can best be archived for future use by both the industry and the wider research community.

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Appendix A PfPI costs of blanket speed restrictions for 2011

Table 1 - PfPI costs of blanket speed restrictions for 2011

Date	Route Name	Delivery Unit Name	Incident Reason Description	PfPI Minutes	PfPI Costs
03/02/2011	LNW	CARLISLE	Blanket speed restriction for extreme heat or high wind	12	63
04/02/2011	**LNE**	NEWCASTLE	Blanket speed restriction for extreme heat or high wind	279	25,761
04/02/2011	**LNE**	YORK	Blanket speed restriction for extreme heat or high wind	346	25,834
04/02/2011	**LNW**	CARLISLE	Blanket speed restriction for extreme heat or high wind	10	102
05/02/2011	**LNE**	NEWCASTLE	Blanket speed restriction for extreme heat or high wind	3	353
05/02/2011	**LNE**	YORK	Blanket speed restriction for extreme heat or high wind	6	439
07/02/2011	**LNE**	DONCASTER	Blanket speed restriction for extreme heat or high wind	307	22,001
10/03/2011	**LNE**	DONCASTER	Blanket speed restriction for extreme heat or high wind	25	2,468
10/03/2011	**LNE**	LEEDS	Blanket speed restriction for extreme heat or high wind	7	320
10/03/2011	**LNE**	NEWCASTLE	Blanket speed restriction for extreme heat or high wind	54	4,319
10/03/2011	**LNE**	YORK	Blanket speed restriction for extreme heat or high wind	240	14,103
23/05/2011	**LNE**	NEWCASTLE	Blanket speed restriction for extreme heat or high wind	202	6,365
23/05/2011	**Scotland**	EDINBURGH	Blanket speed restriction for extreme heat or high wind	3,062	112,542

Table 1 - PfPI costs of blanket speed restrictions for 2011

Date	Route Name	Delivery Unit Name	Incident Reason Description	PfPI Minutes	PfPI Costs
23/05/2011	**Scotland**	GLASGOW	Blanket speed restriction for extreme heat or high wind	424	5,194
23/05/2011	**Scotland**	MOTHERWELL	Blanket speed restriction for extreme heat or high wind	1,849	32,527
23/05/2011	**Scotland**	PERTH	Blanket speed restriction for extreme heat or high wind	853	11,719
24/05/2011	**Scotland**	EDINBURGH	Blanket speed restriction for extreme heat or high wind	0	0
24/05/2011	**Scotland**	GLASGOW	Blanket speed restriction for extreme heat or high wind	5	87
24/05/2011	**Scotland**	MOTHERWELL	Blanket speed restriction for extreme heat or high wind	17	296
03/06/2011	**Kent**	LONDON BRIDGE	Blanket speed restriction for extreme heat or high wind	27	425
04/06/2011	**Kent**	LONDON BRIDGE	Blanket speed restriction for extreme heat or high wind	3	46
26/06/2011	**Anglia**	ROMFORD	Blanket speed restriction for extreme heat or high wind	89	3,990
26/06/2011	**Wessex**	EASTLEIGH	Blanket speed restriction for extreme heat or high wind	194	3,791
27/06/2011	**Anglia**	ROMFORD	Blanket speed restriction for extreme heat or high wind	193	7,999
02/07/2011	**Scotland**	EDINBURGH	Blanket speed restriction for extreme heat or high wind	6	130
04/07/2011	**Anglia**	ROMFORD	Blanket speed restriction for extreme heat or high wind	8	233
05/07/2011	**Anglia**	ROMFORD	Blanket speed restriction for extreme heat or high wind	17	870
11/07/2011	**Kent**	ASHFORD	Blanket speed restriction for extreme heat or high wind	12	41
02/08/2011	**Anglia**	ROMFORD	Blanket speed restriction for extreme heat or high wind	389	15,773
03/08/2011	**Anglia**	ROMFORD	Blanket speed restriction for extreme heat or high wind	188	8,087
12/09/2011	**LNE**	NEWCASTLE	Blanket speed restriction for extreme heat or high wind	408	23,352

Table 1 - PfPI costs of blanket speed restrictions for 2011

Date	Route Name	Delivery Unit Name	Incident Reason Description	PfPI Minutes	PfPI Costs
12/09/2011	**LNE**	YORK	Blanket speed restriction for extreme heat or high wind	20	2,354
12/09/2011	**LNW**	CARLISLE	Blanket speed restriction for extreme heat or high wind	1,312	34,874
13/09/2011	**LNW**	CARLISLE	Blanket speed restriction for extreme heat or high wind	6	32
29/09/2011	**Anglia**	TOTTENHAM	Blanket speed restriction for extreme heat or high wind	88	1,602
30/09/2011	**Anglia**	TOTTENHAM	Blanket speed restriction for extreme heat or high wind	46	840
01/10/2011	**Anglia**	ROMFORD	Blanket speed restriction for extreme heat or high wind	6	473
07/12/2011	**LNE**	YORK	Blanket speed restriction for extreme heat or high wind	40	3,903
08/12/2011	**LNE**	HITCHIN	Blanket speed restriction for extreme heat or high wind	50	4,904
08/12/2011	**LNE**	NEWCASTLE	Blanket speed restriction for extreme heat or high wind	145	5,375
08/12/2011	**LNE**	YORK	Blanket speed restriction for extreme heat or high wind	1,140	34,758
08/12/2011	**LNW**	CARLISLE	Blanket speed restriction for extreme heat or high wind	717	25,403
08/12/2011	**LNW**	PRESTON	Blanket speed restriction for extreme heat or high wind	2,021	60,293
08/12/2011	**LNW**	SANDWELL & DUDLEY	Blanket speed restriction for extreme heat or high wind	5	114
12/12/2011	**LNW**	STAFFORD	Blanket speed restriction for extreme heat or high wind	2	45
13/12/2011	**LNE**	NEWCASTLE	Blanket speed restriction for extreme heat or high wind	516	29,260
13/12/2011	**LNW**	CARLISLE	Blanket speed restriction for extreme heat or high wind	171	7,822
13/12/2011	**LNW**	PRESTON	Blanket speed restriction for extreme heat or high wind	162	5,563
13/12/2011	**Scotland**	PERTH	Blanket speed restriction for extreme heat or high wind	3,144	46,402

Table 1 - PfPI costs of blanket speed restrictions for 2011

Date	Route Name	Delivery Unit Name	Incident Reason Description	PfPI Minutes	PfPI Costs
14/12/2011	**LNE**	NEWCASTLE	Blanket speed restriction for extreme heat or high wind	69	4,238
14/12/2011	**LNW**	PRESTON	Blanket speed restriction for extreme heat or high wind	0	0
14/12/2011	**Scotland**	PERTH	Blanket speed restriction for extreme heat or high wind	5	54
28/12/2011	**LNE**	NEWCASTLE	Blanket speed restriction for extreme heat or high wind	282	12,493
			Total	**19,182**	**610,031**

RSSB Research Programme
Block 2 Angel Square
1 Torrens Street
London
EC1V 1NY

enquirydesk@rssb.co.uk

www.rssb.co.uk/research/Pages/main.aspx