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The impacts of the 28 June 2012 storms on UK road and rail transport

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ABSTRACT: Extreme weather events can cause severe disruption to transport systems, greatly reducing the ability to maintain important social and economic functions such as the delivery of goods and materials within the supply chain. There is a need for greater qualitative and quantitative understanding of how transport systems respond under adverse conditions, to inform event management and to aid adaptation actions. The present study uses the intense storms of 28 June 2012 as a case study to present a novel exploration of the impacts of an extreme event using high spatial and temporal resolution transport data for the UK road and rail networks, as well as weather data from the UK Meteorological Office's MIDAS surface station network and NIMROD weather radar. This event caused widespread disruption, severing the main rail links between England and Scotland and causing 10 000 delay minutes to train services throughout the country, as well as causing reduced speeds on local roads and motorways. The present study describes the meteorological situation in the build-up to and during the event, and uses Network Rail train delay data to visualize the way in which the failure of several sections of critical transport infrastructure caused disruption that propagated quickly through the rail network of Great Britain. Highway Agency motorway speed data are used to quantify the impact of this event on the M6 motorway in the West Midlands. Ways in which the insights gained from these data can be used to aid the transport sector in the prioritization of adaptation actions are discussed.

KEY WORDS transport; extreme events; delay propagation; climate change adaptation; data visualization; weather

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1. Introduction

Disruption to transport caused by weather can have severe impacts on the economy and society of a given region or country. A notable recent example of this has been the UK winter of 2013–2014, the wettest winter on record in England and Wales (Met Office, 2014), which caused widespread and severe impacts including flooding and disruption to road transport in the Somerset Levels and the collapse of the iconic South Devon Railway sea wall at Dawlish, severing rail access to and from the county of Cornwall and much of Devon. Owing to the important social and economic functions of transport, such as the maintenance of increasingly spatial-extended social networks (Banister, 2011) and the delivery of goods and materials within the supply chain (Hesse and Rodrigue, 2004), there has been an increasing interest in the resilience of transport networks, both in terms of protecting current infrastructure and operations, and also in terms of adapting to potentially more challenging future climates. However, the way in which transport reacts to weather has been shown to require further quantitative and qualitative research (Koetse and Rietveld, 2009; Jaroszweski *et al.*, 2010). To manage effectively the impact of current and future weather, a better understanding of a wide range of interactions between weather and transport including the physical relationships between weather and infrastructure failure and the behavioural relationships between weather and driver behaviour is required. Importantly, a better understanding of how the weather-related effects of damage to critical transport infrastructure propagate through the wider transport systems is needed, as this would both aid better event management and inform the prioritization of adaptation work on particularly critical sections of the system.

The intense storms of 28 June 2012, described by Clark and Webb (2013), provide an example of an extreme weather event which caused severe damage to several critical sections of the UK surface transport infrastructure and resulted in nationwide disruption. The present study describes the impacts of the 28 June storms through available meteorological and media sources, but for the first time uses delay and timing data from the rail network and traffic speed data from the motorway network to visualize and explore in detail the impacts and propagation of disruption following an extreme weather event. It also suggests ways in which the increasing amounts of data created and captured by the transport sector can be better used to identify and prioritize critical transport infrastructure for adaptation to current and projected climates.

2. Meteorological situation

Conditions in the build up to the 28 June storms were extremely wet across most of the country; April 2012 was the second wettest on record in England and Wales (Eden, 2012a) whilst June ended as the wettest on record (Eden, 2012b). Weather across the UK on the morning of 28 June 2012 was dominated by a warm, dry air mass carried by a southerly wind from Spain and France during the night. During the morning of 28 June, a cold front moved in from the Atlantic and travelled across the UK in a northeasterly direction. Where the cold front and warm air mass met, uplifting of air caused cumulonimbus clouds and a line of thunderstorms to form, starting in South Wales at around 0800 BST (UTC +1) and progressing through the Midlands, Lincolnshire and towards the Wash, bringing heavy precipitation, hail, lightning and high

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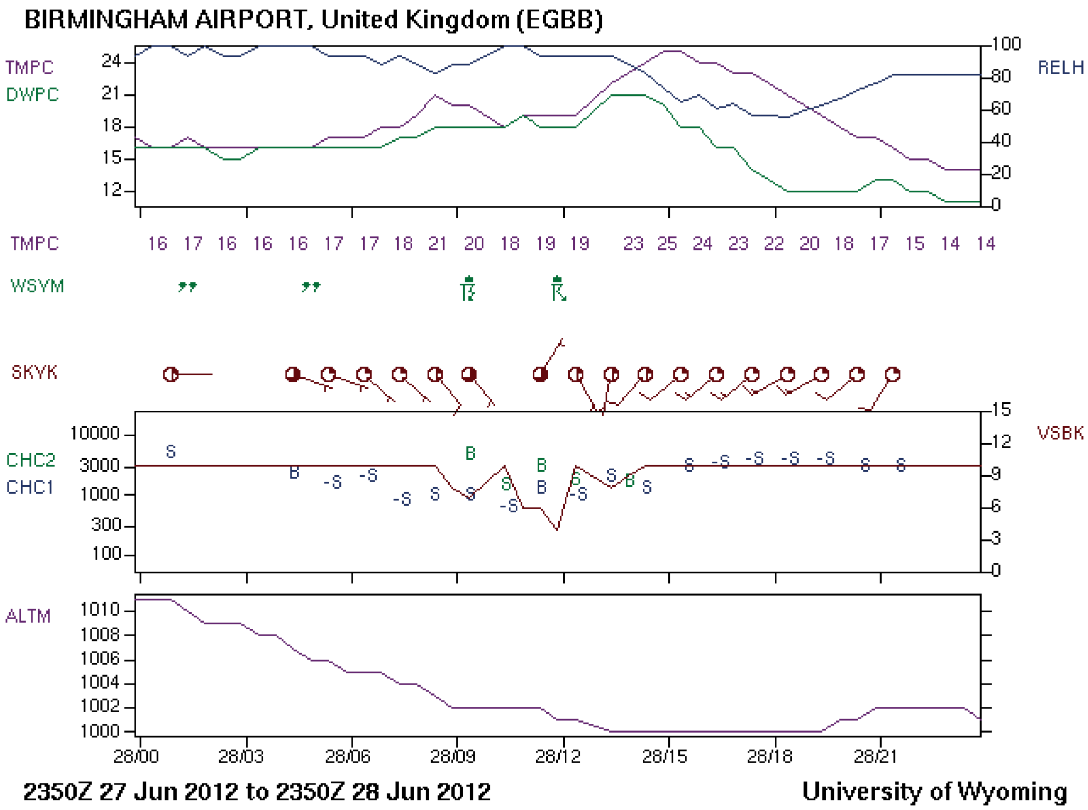

Figure 1. Meteogram of recorded weather in Birmingham, 28 June 2012 (University of Wyoming, 2012a).

winds. The storm passed over Birmingham around 1000 BST and was characterized by a sharp change in wind direction and intense precipitation (Figure 1).

Upper air observations for Nottingham were taken at 1100 BST, which coincided with the time at which thunderstorms were particularly active over the East Midlands (University of Wyoming, 2012b). The parameters give an estimation of the atmospheric situation and several give a strong indication of the likelihood of a thunderstorm. Cumulonimbus clouds form when the Showalter Index, a measure of local static stability is <4, which is the case in this instance. In addition, the convective available potential energy was 397.1 J kg^{-1}, exceeding the value of 300 J kg^{-1} that generally indicates the potential for thunderstorms. A detailed exploration of a similar atmospheric sounding on this day is given by Clark and Webb (2013).

A second sequence of thunderstorms was triggered later in the day in North West England around 1200 BST, passing through the Lake District and reaching Newcastle at around 1600 BST, again interacting with the warm, moist air continuing to dominate the UK. The front remained over Newcastle and its surrounding areas for several hours, bringing a prolonged period of intense precipitation and lightning. Again, a sudden change in wind direction was observed at the time of the thunderstorm as well as a reduction in atmospheric pressure as the low pressure system behind the cold front moved through. Precipitation during the thunderstorms was intense with some areas receiving up to 40 mm h^{-1}. Across the UK, over 1000 lightning strikes were detected in the UK during a 5 min period and over 50 000 were recorded during the day (Met Office, 2012a). Figure 2 shows the location and timing of lightning strikes on 28 June, representing the track and timing of the storms.

3. Impacts on transport

Heavy rain for 28 June had been predicted with the UK Met Office issuing ‘yellow’ warnings for rain for much of the UK, advising the public to ‘be aware’ of severe weather:

> *After heavy rain in parts of southern Scotland overnight, further areas of thundery rain will move north across northern England and Scotland during Thursday. The rain is expected to become heavy and persistent during the afternoon and evening across southern and eastern Scotland, whilst at the same time isolated thunderstorms are expected to develop across the north Midlands and northern England. The public should be aware that localised surface water flooding may occur.* (Met Office, 2012b)

For transport during these rainfall events, the yellow warnings indicate that there are likely to be wet road surfaces as well as some local disruption to travel causing increased journey times (Met Office, 2012c), particularly in areas where there have been previous problems with flooding. However, as will be demonstrated, severe infrastructural damage and flooding at several key locations led to a situation where disruption propagated widely throughout the transport network of Great Britain.

3.1. Rail

Rail transport was affected in a number of places with many services being suspended as a result of flooding and landslips. Of particular significance were the closures of sections of both the East Coast and the West Coast Mainlines (ECML and WCML),

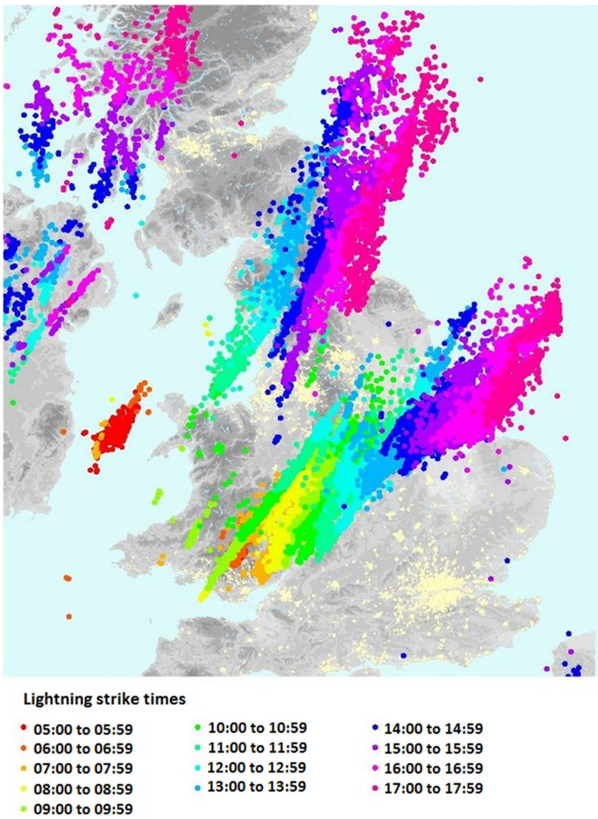

Figure 2. Recorded lightning strikes during 28 June 2012 (© 2012 Crown copyright, Met Office).

UK's busiest long-distance rail routes and sole rail links between England and Scotland. On the WCML, extreme downpours triggered landslips and flooding in the Cumbria region. Flooding was also observed on the line near Oxenholme at ~1500 BST. These incidents caused the WCML to be impassable on both tracks for the rest of the day, and also caused a train to be trapped between incidents for over 2 h. Large queues of passengers formed at Glasgow Central, which were quickly exacerbated by the closure of the ECML and hence removal of the alternative rail route into England.

The impacts of this incident on the rail network are illustrated spatially and temporally in Figure 3 and Video S1 (Supporting information). Two types of data are used; firstly NIMROD weather radar data which shows the bands of rainfall moving across the country with the cold front, and secondly Network Rail TRUST (Train Running System TOPS) delay data, used here to display the timing and location of the individual train delays attributed to a sub-ballast landslip at Tebay and a flooding incident at Oxenholme along with the magnitude of delays in minutes. The TRUST system records the times trains pass specific timing points, typically stations and important junctions. If a train passes a timing point later than scheduled, the number of 'delay minutes' (defined as the difference between scheduled and recorded times) is recorded and attributed to a given incident where appropriate. These attributions are recorded at the time of the incident and are later reviewed and revised where appropriate. Trains are affected either directly by an incident, such as being held ahead of submerged tracks or indirectly by being held up by another delayed train. From these data it is possible to show the spatial propagation of delays related to this event, identifying the spread of the disruption along the WCML. Initially, these impacts are isolated to the WCML, albeit spreading quickly throughout the entire length of the route. However, around 6 h into the event (2100 BST) the disruption began to propagate into Wales along the North Wales Coast rail line and east across the Pennines as delays knocked on to other services and train crews became displaced. Overall this event accounted for 2500 minutes of delay to train services. Although the line was repaired overnight and reopened in the morning, the WCML suffered further problems on 29 June due to damage to overhead power lines between Carstairs and Lockerbie caused by the previous day's heavy rain and flooding, particularly the movement of masts (in one case the overhead line mast was washed away by the flood water). This resulted in a second closure of the line.

At around 1600 BST, flooding in the Newcastle area and a landslip on the line near Berwick caused the partial closure of the ECML. Figure 4(a) and Video S2 show how delays propagated southwards towards London and southwest to Birmingham following these incidents. This event caused particular disruption around the important hub station of York, with delays propagating both to London along the ECML as well as to Birmingham and the South West on the Cross Country Route. Overall, there were 3500 recorded delay minutes attributed to this incident. There was also severe local disruption in Newcastle, with the Tyne and Wear Metro service completely suspended on 28 June due to the extreme rainfall, and buses being used to replace trains on part of the network.

Other disruption included widespread delays propagating in several directions from flooding at Barnt Green Junction near Birmingham (Figure 4(b) and Video S3). Owing to the large number of local and national routes passing through this junction and its proximity to Birmingham New Street, knock-on delays as far as Penzance, South Wales, Liverpool, Southampton, London and Edinburgh were recorded, amounting to 4900 delay minutes, as well as causing many cancellations. The high precipitation triggered a landslide which led to the derailment of a freight train in the Scottish Highlands near Tulloch. This incident caused the closure of the line for repair work on the track and to stabilize the slope, with the line not opening again until 10 July. The remote nature of the location necessitated the deconstruction, and eventual scrapping of the locomotive *in situ*. Overall, events on 28 June caused 10 000 weather-related minutes delay with the impacts lasting until mid-July.

3.2. Road

Roads across the country were also affected with many having to be closed as a result of flooding, causing delays to journeys and disruption to public transport. The M6 motorway in Birmingham was severely affected during the thunderstorm, and further main routes into the city had to be closed. Reductions in traffic speeds on motorways across the Midlands were reported widely. The HATRIS database (Highways Agency TRaffic Information System) contains information about traffic speeds and flows on the UK motorway network at a 15 min temporal resolution on each junction to junction section of the motorway, allowing for the identification of any reductions in speed. Data were obtained for 28 June and again coupled with NIMROD precipitation radar data. Reductions in speed which were likely to have occurred as a result of the precipitation during the thunderstorms were identified. Maps were created for the West Midlands showing the M6 motorway and the precipitation at 15 min intervals, allowing precipitation values to be extracted for each junction-to-junction section of the motorway, as shown in Figure 5.

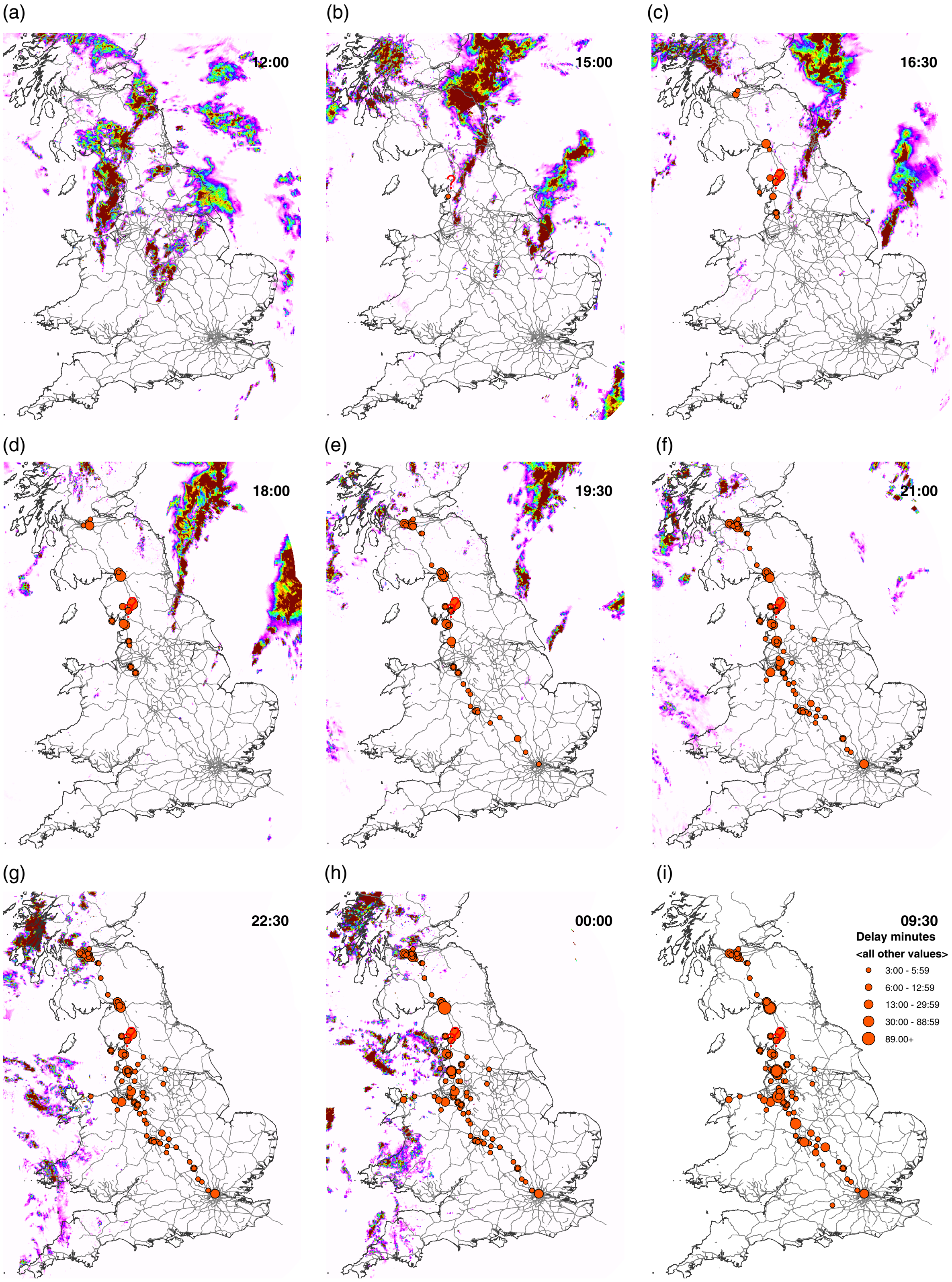

Figure 3. Recorded train delays from the TRUST database and NIMROD weather radar images for the Cumbria landslip event on 28 and 29 June 2012. [Correction added on 5 January after original online publication: part (i) has been replaced to correct an error in the scale.]

The precipitation and traffic speed values for junctions 5 and 6 of the M6 on the morning of 28 June are shown in Figure 6, which shows a clear peak in precipitation immediately before a large reduction in speed. Speeds continued to fall following the passage of the cold front, recovering shortly afterwards. The peak in precipitation shown here at 0930 BST also shows how intense the precipitation was during the storms; for this particular junction the peak value was 37 mm h^{-1}. The problems illustrated both by the speed data and from the news articles published at the time indicate that as well as the type of autonomous speed

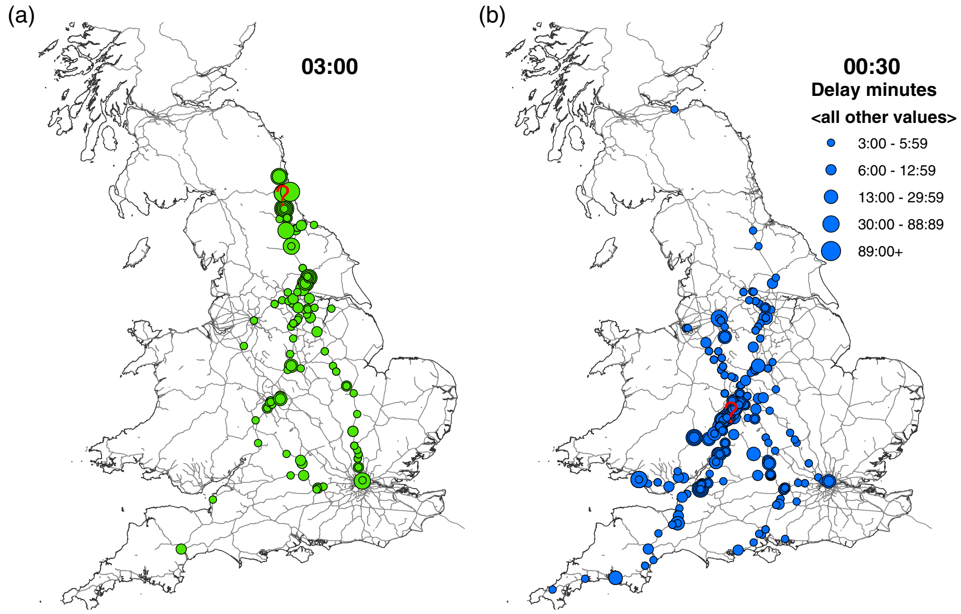

Figure 4. Recorded train delays from the TRUST database and NIMROD weather radar images for the (a) Barnt Green and (b) Newcastle flooding events. [Correction added on 5 January after original online publication: parts (a) and (b) have been replaced to correct an error in the scale.]

reductions due to reduced visibility (Hooper *et al.*, 2014); there were extensive problems with drainage on that day. Although drains may not have been blocked, they were unable to cope with the volume of water which fell onto the carriageways during the storms. Similar problems with flooding were reported across much of the Midlands and the North East.

Safety was another issue, with motorists becoming trapped due to fast rising water, resulting in an increased volume of calls to the fire service. In Leicestershire, fire fighters responded to 190 calls in 4 h, more than five times the average number (This is Leicestershire, 2012a). Similarly, fire fighters in Hereford and Worcestershire responded to 18 calls from drivers trapped in their cars, with one driver having to be rescued by boat (BBC, 2012). Three people were injured in storm-related incidents in Coalville, Loughborough and Leicester. Many roads were also obstructed by debris with Redditch ring road being closed after two trees fell onto the carriageway and there was also a fallen tree on the M56 motorway.

The hail storm across Leicestershire explored by Clark and Webb (2013) caused particular problems for motorists with large hail stones damaging cars and leading to a number of insurance claims being made; the AA (Automobile Association) reported receiving 29 claims within 30 min of the 10 min hail storm, and Admiral (insurers) had 50 claims within an hour (Guardian, 2012). Emergency services were affected with two ambulance windscreens being broken by hail (This is Leicestershire, 2012b). The weather-related congestion also caused knock-on impacts for other types of infrastructure, illustrating important interdependencies. For example, in North East England thousands of homes were left without power after electricity substations were flooded. As roads were gridlocked due to flooding and obstructions, engineers were unable to reach the substations, meaning around 2500 properties were still without power on the evening of 28 June (BBC, 2012).

4. Discussion

The presented analysis clearly illustrates how weather can severely impact transport operations, both at the immediate site of the event, and also throughout the wider national transport network. These insights have potential implications for the way in which transport data can be used both to manage weather-related disruption events, and also as an aid to informing the adaptation of critical transport infrastructure to climate change and extreme weather. For example, if looked at as an ensemble of all observed events on a particular line section, the delay data for the rail network offers a potentially powerful resource for indicating the likelihood of the disruption from an event propagating to other parts of the network. From this it would be possible to identify critical links and nodes where a combination of network topology and timetable means that disruption tends to propagate widely. This idea is discussed by Jaroszweski *et al.* (2014) in the context of urban transport systems, but has similar relevance to national transport networks. This also links to the recommendations made in the Department for Transport's (DfT) review on weather-related transport resilience, known as the 'Brown Review' (DfT, 2014), which was written in response to the winter storms and floods of 2013–2014. The review highlights the need for the identification of critical 'single points of failure' that risk severing important social and economic links. This would allow infrastructure managers and train operating companies to develop operational and infrastructural contingency to reduce the likelihood of widespread disruption, including emergency timetables, plans for alternative means of transfer of train crews and the introduction or reintroduction of relief track in critical locations. For example, ensuring that emergency diesel engines are available in lines with a high risk of weather-related disruption to overhead lines is one means of contributing to service continuity.

The supply chain for emergency repair materials, engineers and maintenance crews to critical locations is also of key importance and was observed to work well during the events described in the present study. However, a systematic method of assessing the current contingency plans throughout the system is essential. This is a multimodal concept and should be considered in concert with similar analyses of criticality for the road network, and would allow contingency and redundancy to be built into the transport system as a whole, rather than for one mode in

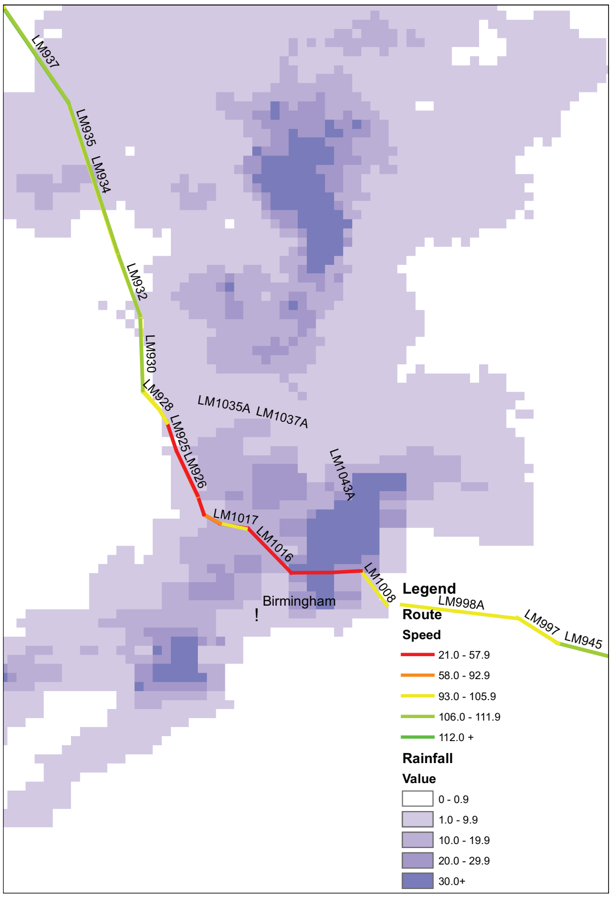

Figure 5. NIMROD precipitation radar data and HATRIS speed data (km h^{-1}) for the M5 motorway around Birmingham on 28 June 2012, 0930 h.

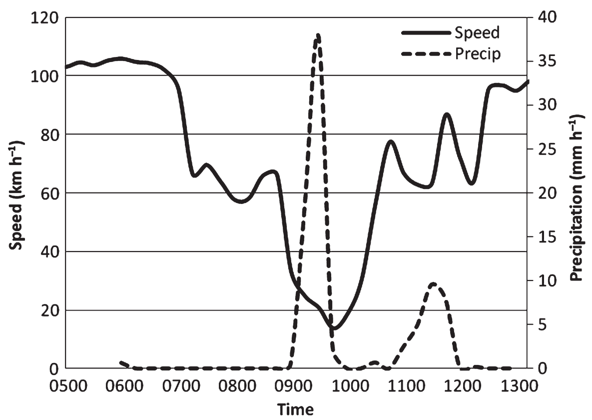

Figure 6. 15 Min average motorway traffic speeds and precipitation values for junctions 5 and 6 of the M6 on 28 June.

isolation. In certain cases where organizational and operational plans are not sufficient, this may lead to the decision to build new infrastructure such as diversionary track where operational and organizational options are not sufficient.

In the longer-term, the identification of critical sections of the network could form a key component of the decision-making process involved in climate change adaptation. One potential way of using these data is to incorporate the observations of delay propagation into the risk-mapping process. Risk mapping involves the creation of vulnerability and hazard maps. Adaptation work would be prioritized where areas of high projected hazards (from climate change projections) correspond with high vulnerability (a combination of asset condition, geology, hydrology and network-criticality). To be of most use, ideally the climate change projections would not only project the future frequency and intensity of meteorological hazards in a given location, but also give an indication of the change in storm intensity, frequency and track, as transport systems are particularly vulnerable to spatial hazards that damage several key sections of infrastructure simultaneously (Wilkinson *et al.*, 2012). The sections of the WCML and ECML affected by the 28 June event are a good example of this, as the predominant storm track and the relative proximity of these sections of transport infrastructure means closure of both lines in this area is not uncommon.

5. Conclusions

The present study explored and quantified the impact of a notable extreme weather event on UK transport using previously underutilized transport data. It has demonstrated clearly how the failure of infrastructure at a number of key locations can effectively cut off access to large parts of a country by certain modes of transport and cause knock-on delays that can propagate throughout the national transport system very quickly. It also highlights the knock-on effect on other important sectors when access, particularly by the roads, is not available for repair work. In this case it was the energy sector, but rail transport is also vulnerable to disruption to the road network, as this is the main access route for repair and maintenance crews, station staff and signallers. It is suggested that by looking at ensembles of delay propagation at different sections of the network, the data presented in the present study may also have further uses for the management of extreme events and the prioritization of adaptation work in critical locations.

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Supporting information

The following material is available as part of the online article:

Video S1. Animation showing recorded train delays from the TRUST database and NIMROD weather radar images for the Cumbria landslip incident on 28 and 29 June 2012.

Video S2. Animation showing recorded train delays from the TRUST database and NIMROD weather radar images for the Newcastle flooding incident on 28 and 29 June 2012.

Video S3. Animation showing recorded train delays from the TRUST database and NIMROD weather radar images for the Barnt Green flooding incident on 28 and 29 June 2012.

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