Paper for WCRR 2011

Tomorrow’s Railway and Climate Change Adaptation (TRaCCA)

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1. Introduction

The Royal Commission on Environmental Protection study ‘Adapting Institutions to Climate Change\(^{1}\)’, has identified ‘a growing recognition at a global, European and UK level of the need to adapt to climate change’. However, despite commitments to control the effects of climate change, by reducing carbon emissions for example, it is recognised that some impacts are inevitable and action will be necessary to mitigate the negative impacts.

In common with other critical infrastructure upon which society depends, the providers of railway transport systems will firstly need to assess the disruptive effects of critical weather on the performance of the existing transport system, in order to inform the development of appropriate policies and standards for mitigation, which take the impacts of climate change into account.

Within the UK railway industry, work has been ongoing over the past decade to identify the impacts of critical weather events on the railway\(^{2,3}\), to establish what are the impacts of climate change\(^{4,5}\) and to develop methodologies for adaptation of the railway to mitigate the impacts of critical weather and climate change\(^{6}\).

The research discussed in this paper\(^{7}\), has built on the knowledge from previous research aimed at development of the tools required by the GB railway industry, to provide a reliable railway into the future. The methodology has been developed by the Met Office Hadley Centre.

2. Drivers for research

Critical weather events in the last few years (the Cumbrian floods of 2009 for example) have demonstrated that we have insufficient understanding of weather effects on our infrastructure, rolling stock, passengers and staff, to permit informed judgements to be made concerning the adaptation policy that is necessary to deliver a reliable railway into the future.

Figure 1. Flooded house at Keswick
The railway industry needs to know how the current and future climate will affect the ability to achieve and deliver:

- a safe railway;
- a highly reliable railway;
- increased capacity;
- value for money;
- a ‘predict and prevent’ ethos.

The Climate Change Act\(^8\) has implemented a process by which statutory authorities, such as Network Rail, are required to comply with formal reporting requirements in respect of climate change adaptation. In order to undertake the required reporting process, it is firstly necessary to identify the key activities that are required, to develop a reliable method for the prediction of climate change impacts. Such a method may then be applied, in connection with the planning process, to evaluate the current vulnerability of the railway system, to develop the options for adaptation and to identify the requirements for revision of design standards and the policies that are to be adopted for management.

The key components of the planning process for adaptation, are summarised in Table 1 below:

<table>
<thead>
<tr>
<th>Planning Component</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical weather events</td>
<td>Knowledge and understanding of impact on railway system</td>
</tr>
<tr>
<td>Critical components of railway system</td>
<td>Knowledge and understanding of vulnerability to critical weather events</td>
</tr>
<tr>
<td>Prediction of climate change impact</td>
<td>Methodology for predicting the impact of specific critical weather events on components of the railway system</td>
</tr>
<tr>
<td>Development of adaptation options</td>
<td>Permits evaluation of different adaptation policies</td>
</tr>
<tr>
<td>Design standards</td>
<td>Identification of changes to design standards to mitigate the impact of climate change</td>
</tr>
<tr>
<td>Management policy</td>
<td>Identification of changes to management policy to mitigate the impacts of climate change</td>
</tr>
</tbody>
</table>

Table 1. Planning for climate change adaptation

Previous research has highlighted the importance of appropriate information upon which to base decisions that are necessary for the adaptation and management of the railway infrastructure to cope with the impacts of climate change. The achievement of future reliability is dependent upon appropriate decision making for the planned maintenance and, the modification or replacement, of railway system components (infrastructure and rolling stock for example), that are vulnerable to impacts from climate change, at a reasonable cost.

The development of a generic method for assessment of the future impact of climate change, will permit the development of options for managing individual railway assets in the longer term. It will require knowledge of current critical weather impacts on vulnerable assets and a weather modelling capability to predict the impacts due to future climate conditions. The prediction...
methodology developed, will be able to make use of the very latest UK Climate Projections (formerly known as UKCIP08) published in 2009 by the UK Climate Impacts Programme\textsuperscript{[9]}.

3. The TRaCCA project

The GB DfT railway Technical Strategy Advisory Group (TSAG), understood the value in the development of an adaptation strategy, including the development of an Adaptation Policy Evaluation Tool (APET), as a means of achieving increased reliability and competitiveness of the railway system and at the same time, taking into account the potential future impacts of climate change on critical weather events. It also provides a means of achieving compliance with the reporting process imposed on Network Rail under the Climate Change Act\textsuperscript{[8]} provisions.

It was understood that the principles of climate change adaptation planning (see Table 1), could be applied, not only to infrastructure, but also to the railway system as a whole. In this way, the benefits of adapting, infrastructure, rolling stock, energy transmission systems, signalling and communications systems and operational policies, to cope with the impact of climate change on their performance and reliability, can be considered holistically, as well as for specific components of the railway system. The principles of climate change adaptation, set out in Table 1, have already been considered for the example of sea defence structures and, the findings of that research\textsuperscript{[6]} have demonstrated the possibility for extension of the principles to the railway as a whole.

The research project Tomorrow’s Railway and Climate Change Adaptation (TRaCCA)\textsuperscript{[7]}, was devised to satisfy the need for predictive capability for climate change impacts across the railway system. It is a £0.75M project, the budget for which is provided through the UK Department for Transport (DfT) funded Research and Development (R&D) programme managed by RSSB on behalf of the railway industry.

The research is being undertaken in several phases as follows:

- Phase 1 Project definition
- Phase 2 Preliminary analysis and specification development
- Phase 3 Detailed analysis and preliminary development of adaptation policy evaluation tool

Phases 1 and 2 of the project are already completed and will be reported upon in this paper.

Phase 1 - Project definition

The key deliverables planned within Phase 1, are summarised in table 2 below:

<table>
<thead>
<tr>
<th>Phase 1 Deliverables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confirmation of the priority topic areas (with infrastructure, TOC, maintenance and operations specialists)</td>
</tr>
<tr>
<td>Confirmation of data availability (including data for performance, safety, rolling stock, systems, and operations)</td>
</tr>
</tbody>
</table>
A key element of the methodology adopted for the Phase 1 project, was a series of workshops to which relevant railway system specialists were invited, for the purpose of establishing the ‘priority topic areas’, for which Adaptation Policy Evaluation Tools (APETs) should be developed. Seven workshops were held with the participation of, the UK Met Office Hadley Centre, railway asset management specialists from Network Rail (Engineering, Operations and Maintenance) and the Association of Train Operating Companies (ATOC). At these workshops, potential risks to the railway, taking in to account the effects of predicted climate change impacts, were identified.

Following the workshops, a review and moderation exercise produced a summary list of priorities, which was then further reviewed and modified by the workshop attendees. This resulted in a confirmed list of the ‘priority topic areas’ that were considered likely to pose the greatest risk to the performance and safety of the railway, taking into account the potential impact of climate change, but also importantly, for which data on current performance in critical weather events was available.

The list of ‘priority topic areas’ which were taken forward for study within Phase 2, are summarised in Table 3.

<table>
<thead>
<tr>
<th>Climate Impact Group</th>
<th>Cluster</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat</td>
<td>Track</td>
<td>Management of track buckle risk</td>
</tr>
<tr>
<td>Heat</td>
<td>Track</td>
<td>Reduced window of opportunity to carry out maintenance/renovations work due to heat</td>
</tr>
<tr>
<td>Heat</td>
<td>People</td>
<td>Passenger health and impact on freight from train failure in extreme temperatures, including heat and cold</td>
</tr>
<tr>
<td>Heat</td>
<td>People</td>
<td>Staff working conditions, eg: use of heat watchmen</td>
</tr>
<tr>
<td>Heat</td>
<td>Power/Telecoms/Signalling</td>
<td>i. Floating electrical earth leading to stray earth currents caused by dry ground/low groundwater; ii. Heat (solar gain) affecting lineside equipment; iii. Sag in tethered overhead line systems at terminal stations</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Fluvial flood</td>
<td>Track and lineside equipment failure</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Groundwater flood</td>
<td>Track and lineside equipment failure</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Pluvial flood</td>
<td>Track and lineside equipment failure</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Fluvial flood</td>
<td>Scour and water effects at bridges</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Fluvial flood</td>
<td>Scour at embankments due to high river levels and culvert washout</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Fluvial flood</td>
<td>Safety of workforce carrying out inspections during an extreme flood event</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Pluvial flood</td>
<td>Landslips</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Fluvial flood</td>
<td>Accessibility of fleet and of maintenance depots</td>
</tr>
<tr>
<td>Insolation/heat/rainfall/wind</td>
<td>Vegetation</td>
<td>Change in type, falling trees causing obstructions, poor adhesion, and track-circuit non-activation</td>
</tr>
<tr>
<td>Insolation/v/vegetation</td>
<td></td>
<td>Leaves on line affecting track circuitry – signal showing</td>
</tr>
</tbody>
</table>
Table 3: Confirmed Priority Topic Areas

<table>
<thead>
<tr>
<th>Heat/rainfall/wind</th>
<th>‘clear’ when track section occupied (SCWO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea level rise and storms</td>
<td>Coastal and estuarine defences</td>
</tr>
</tbody>
</table>

NOTE – The highlighted areas are those for which further explanation is provided in this paper.

The key deliverables planned within Phase 2, are summarised in Table 4 below:

### Phase 2 Deliverables

- **Mathematical models** for the priority topic areas for the decades 2010s, 2020s, 2030s, 2040s
- **A high-level impact assessment** as required by Government for 30th September 2010
- **Recommendations** for potential ‘quick wins’ in terms of adaptation and procedural options for dealing with the impacts of current weather patterns
- **Preliminary recommendations** for asset management policy and planning for Control Periods CP5 – CP8
- **A specification** for a tool to enable the rail industry to evaluate policy options (Adaptation Policy Evaluation Tool) for adaptation and weather resilience for priority and other topic areas
- **Detailed specifications and costings** for Phase 3
- **A climate change adaptation seminar** to raise awareness and to inform the rail industry of likely climate change issues.
- **A report** summarising the above

Table 4. Planned phase 2 deliverables

The Met Office Hadley Centre and Network Rail sector experts, have worked together to identify the key meteorological thresholds of interest for the selected priority topic areas. These have been analysed using the data behind the UK Climate Projections 2009 (UKCIP09)[9], for three time periods (2020s, 2030s and 2040s), relative to a baseline period of 1971 to 2000.

Within Phase 2, innovative techniques have been developed to combine the outputs from climate models with data on actual weather related incidents, and to translate the findings into metrics commonly used across the industry (number of lost work days or train delay minutes for example). In this way, the various sector experts can use the data directly to develop business strategies for a changing world.
Challenge G: An even more competitive and cost efficient railway

For the purpose of establishing the principles and methodology for evaluation of climate change adaptation policy options, the West Coast Main Line (WCML) was used as a case study. This was convenient as the appropriate critical weather event data already existed. The detailed findings and context are set out in the report prepared for Network Rail by the Met Office Hadley Centre\textsuperscript{[10]}. 

4. Case studies – Track buckling and river (fluvial) flooding

For two of the priority topic areas (track buckling and river (fluvial) flooding), the climate science was sufficiently well developed and reliable climate impact data was available, to permit the modelling of climate change impacts. The findings for these studies are described in the following.

Track buckling

Railway track is designed to withstand a range of temperatures but, extremes of high temperature, can cause failure by buckling of jointed and continuously welded rail (CWR), due to overcoming the resistance of the track to the expansion forces. To reduce the risk of track buckling on hot days at particular sites (where work is ongoing or there is a localised weakness), Network Rail manages their track using a system of critical temperatures and corresponding management actions. The key management actions where Critical Rail Temperatures (CRTs) occur at particular sites, are summarised in Table 5:

<table>
<thead>
<tr>
<th>Critical Rail Temperature (CRT) Category</th>
<th>Track management action</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRT(W)</td>
<td>Deployment of heat watchmen to monitor the affected length of track</td>
</tr>
<tr>
<td>CRT(30/60)</td>
<td>30/60 mph speed restriction</td>
</tr>
<tr>
<td>CRT(20)</td>
<td>20 mph speed restriction</td>
</tr>
</tbody>
</table>

Table 5 – Management actions at Critical Rail Temperatures

The CRT is dependent on the condition of the track (that is the degree to which restraint to buckling is available from the surrounding ballast). In the future, the UK is projected to become warmer and therefore, in the absence of change in the track condition, the frequency of track buckle incidents due to temperature extremes, is projected to increase, with a consequential increase in train delays due to the application of speed restrictions.

The methodology applied for this project has involved an assessment of the increase in delay minutes for the 2020s, 2030s and 2040s if no action is taken and, the benefits of improving the track at certain points on the network. It involves an assessment of the relationship between the rail temperature and the air temperature\textsuperscript{11} at which specified actions for particular track conditions are necessary. The specific steps involved in development of the methodology are described in Figure 2:
Challenge G: An even more competitive and cost efficient railway
Figure 2. Overview of methodology for assessing the projected change in track management actions for defined track conditions

The number of heat watchman days and the frequency of speed restrictions being imposed (associated with buckle risk and high temperatures) is projected to increase by the 2040s for all track conditions examined, for the whole of the WCML. For example, for the worst track condition (‘three or more consecutive slurried beds where ballast is not compacted against the sleeper ends’), the number of heat watchman days in the south-east could be twice as many as occurred in the baseline period (2010s), rising from 5 to 7 per year to 7 to 15 per year in the 2040s. Larger differences are possible in Scotland, where the number of heat watchman days in the baseline period is approximately one per summer. This could increase by the 2040s to between 1 and 7 per summer.

**Fluvial flooding priorities**

River (fluvial) flooding occurs when heavy rain falls on an already waterlogged catchment and the watercourse cannot cope with the volume of water draining into it from the surrounding land. Network Rail has identified four priority areas related to river flooding as follows:

- scour and flooding at bridges
- embankment scour and culvert washout
- depot flooding
The flooding mechanism and limitations in the availability of flood vulnerability data, are the same for each of these assets. Therefore a common methodology has been developed, based on an assessment of the change in rainfall that could affect future flood risk and impact on delay to train services.

The methodology has been developed based on consideration of the daily observational rainfall data (Met Office and Network Rail) and rainfall predictions using the Met Office regional climate model (RCM) data. A five step process was involved, the steps for which are briefly described in Figure 3:

**Identify the flooding events**
Which areas have experienced recent problems from flooding?

**Establish the severity of the events**
How do these events compare to other rainfall events in recent history?

**Model the rainfall total threshold**
How can the rainfall events be assessed using the climate model?

**Understand the changing hazard**
How are the rainfall events projected to change into the future?

**Understand the changing risk**
What is known about the present-day effect of flooding events on the rail network?

Several river catchment areas were identified during discussions between Met Office and rail stakeholders, where flood damage had occurred during the last six years.

The severity of the events in these areas was assessed for the 99th percentile rainfall events over a 2-3 day period.

The exceedance of the 99th percentile rainfall corresponding to each event was assessed both for the baseline (present day) period and for the 2020s, 2030s and 2040s.

Recent data for flooding incident delay minutes were assessed and used as the basis for estimating future delays.

Figure 3. Overview of methodology for assessment of the projected change in flooding impacts due to climate change

For the six catchments studied, the multi-day rainfall totals (1-3 days), which resulted in flooding and most disruption of train services, were generally within the 99th percentile value. Overall, the percentage change in frequency of threshold exceedance rainfall total across all river basins, ranged between -20% and +80%. Specifically, for the Severn, Calder and...
Rhymney rivers, the results suggest an increase in flooding events that lead to disruption of train services with time. For other river basins, the results are less clear, with no clear change between the 2020s and 2040s.

Figure 4 shows how the percentage change in threshold exceedance varies through time for each catchment. The red crosses show the percentage change for each of the 11 regional climate model runs, and the black cross and line show the ensemble mean with one standard deviation.

![Figure 4](image)

Figure 4. For two of the events studied (each in different catchments), the percentage difference in threshold exceedance between the baseline and the 2020s, 2030s and 2040s.

The approach adopted for this study is reasonable for the purpose of indicating future change in flooding events, but there are a number of issues that have been identified as requiring further consideration for the purpose of site specific modelling. These are:

1. Detailed hydrological modelling will provide a more realistic assessment of flows affecting particular sites.

2. Extreme rainfall events occur naturally as part of normal climate variation, however climate change may alter the risk of increasing frequency of threshold exceedance events.

3. The study has considered only flooding following rainfall associated with cyclonic frontal systems (depressions) and not the heavy rainfall which is associated with convective extremes in summer.

4. Uncertainty in future climate change predictions remain owing to our limited ability to describe the climate system through a mathematical model and large variability in predictions is obtained.
5. Future work and expected outputs

Phase 3 will involve more ‘Detailed analysis and development of adaptation policy evaluation tool’. The key deliverables planned for Phase 3, are summarised in Table 6 below:

<table>
<thead>
<tr>
<th>Phase 3 Deliverables</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Route-based climate change vulnerability maps</strong></td>
<td></td>
</tr>
<tr>
<td><strong>An interactive mapping visualisation tool</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Adaptation Policy Evaluation Tools</strong> for the priority and other topic areas for use by the rail industry</td>
<td></td>
</tr>
<tr>
<td><strong>Material</strong> for the Government reporting in detail</td>
<td></td>
</tr>
<tr>
<td><strong>Recommendations</strong> for geographically - based Standards development and further research requirements to support this</td>
<td></td>
</tr>
<tr>
<td><strong>Priority climate change impacts</strong> for the whole GB rail industry for the four decades 2010s, 2020s, 2030s, 2040s</td>
<td></td>
</tr>
<tr>
<td><strong>A seminar</strong> to cover the findings of the research</td>
<td></td>
</tr>
<tr>
<td><strong>Guidance</strong> to inform the rail industry of likely climate change issues and how they will be dealt with</td>
<td></td>
</tr>
<tr>
<td><strong>A report</strong> summarising the above</td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Phase 3 deliverables

The completed research will provide a climate change Adaptation Policy Evaluation Tool (APET). The application and effectiveness of the tool will be tested through, a rail industry climate change adaptation seminar to share the research findings and to obtain feedback on its application. Guidance on adaptation will also be developed.

The APET will permit prediction of climate change impacts for selected decadal intervals up to and including the 2040s and facilitate planning for an affordable and cost-effective weatherproofing programme. In principle, the variation in climate change impacts along a route, will provide an opportunity for standards to vary according to the geographical location. Therefore the potential exists to optimise railway system performance according to climate change vulnerability along a route.

The principles applied in the development of the climate change APET, may be illustrated simply through the example of a weather related event which currently results in significant impact to the railway and is likely to worsen when the effects of climate change are taken into account. An example for the case of track flooding is presented in Table 7 below:

<table>
<thead>
<tr>
<th>Critical weather event scenario</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooding resulting in line closure [GE/RT8000, Module 4.1 – moving flood water or 100mm above track – authority to allow trains to run required]</td>
<td></td>
</tr>
<tr>
<td>Current delay minutes – ‘X’ minutes per year</td>
<td></td>
</tr>
<tr>
<td>Future delay minutes – Increase to ‘Y’ minutes per year</td>
<td></td>
</tr>
<tr>
<td>Standards change</td>
<td>Drainage standards – flow capacity increased</td>
</tr>
</tbody>
</table>

Critical water height above track

J.Lane, RSSB & J.Dora, Network Rail, Tomorrow’s Railway and Climate Change Adaptation
to reduce the impact of critical flood events

<table>
<thead>
<tr>
<th>Management policy</th>
<th>Alternative route or alternative transport mode – frequency of diversion or provision of alternative transport increased</th>
</tr>
</thead>
</table>

Table 7. Example of adaptation policy evaluation decision making for track flooding

6. Potential for implementation

The Climate Change Act\(^8\) will require the compliance of Network Rail and the UK rail regulator, the Office of Rail Regulation (ORR), to assess and report on the risks of climate change to rail operations, and to formulate plans to manage these risks. The completed research will provide a method for demonstrating compliance with the climate change legislation.

The Department for Transport (DfT) has published its Adaptation Plan for the rail industry. The TRaCCA project will provide an opportunity to develop the long term planning tools and techniques required for sustainable development and, to quantify the costs and benefits of climate change for particular adaptation strategies for the rail network.

7. Summary and Conclusions

The principle that climate change adaptation policies for the railway system can be determined through a process involving, knowledge and understanding of existing climate impacts and, the availability of a reliable model for prediction of future climate impacts, has been demonstrated through the TRaCCA\(^7\) project and previously for the case of sea defences\(^9\) in the South West of England. This has been possible where the data existing for critical weather events is of sufficient quality and, where the science is sufficiently well known to permit the development of models for prediction of climate change adaptation options.

Further study of some of the priority topic areas, is necessary before the assessment of climate change adaptation options can be completed for all the priority topic areas identified in this study. In these cases, investigation of the link between critical weather events and the impact, needs to be undertaken in order to provide the level of understanding that is necessary for prediction of future climate impacts (the relationship between extreme rainfall and landslips for example). Development of appropriate models requires not only an understanding of the change of frequency and/or severity of critical weather events, but also the way in which the critical weather event influences the probability of an impact on the railway system.

These issues will be important for consideration in future studies.

8. Acknowledgement

The authors would like to thank RSSB for permission to publish this paper and the GB rail industry, particularly the TRaCCA Steering Group, and the Met Office, for their involvement in the work described.
References


