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Report for ORR

"Review of Network Rail's Weather Resilience and Climate Change Adaptation Plans"

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Executive Summary

Weather and longer-term climate change impacts railway operations causing damage to assets, disruption to railway services, and broader socio-economic impacts. The Network Rail Weather Resilience and Climate Change Adaptation (WRCCA) plans manage this risk at Route level, monitored by Office of Rail and Road (ORR) by the 'holding to account' process. This report examines the second revision (2019) of the Route level WRCCA plans to evaluate their efficacy to manage weather and climate risk, and to provide recommendations for improvements to these for future Control Periods (CP) and long-term risk management. The report considers a series of specific questions posed by ORR and examines the WRCCA plans within the context of international good practice in climate adaptation.

The analysis found that there are many strengths to the current WRCCA plans, and they should be considered an example of good practice, globally. Network Rail demonstrates a relatively high maturity in climate resilient planning in comparison to other rail operators internationally, and other sectors. The WRCCA plans are consistent in their approach across the different route regions and provide an evidence-based understanding of current risk to operational performance via an understanding of weather impacts on Schedule 8. Some regions (*e.g.* Western) provided greater level of detail of impacts, stakeholder engagement and action plans.

The WRCCA plans are owned by the Director of Route Asset Management (DRAM), but there was not a clear line of sight from WRCCA plan actions through to asset management. Although a high-level overview of actions to monitor resilience and develop funding for future resilience investments was provided, details of processes, including how resilience improvements would be measured and monitored, was not clear. Processes for longer-term risk management beyond CP6 were not set out, nor were the actions to address interdependencies with other sectors, or sensitivity testing for longer-term high-level climate change.

There are several recommendations **(**numbered '**Rx**'**)** falling under two broad areas of improvement, as outlined below:

Firstly, future WRCCA plans must be broader in scope, considering cross-cutting risks and interdependencies, and the extremes of weather and longer-term climate change, including so-called "worst-case" scenarios.

- **R1:** The WRCCA plan Vulnerability Assessment should consider current and future extreme precipitation.
- **R2:** The river flow uplifts used in the Vulnerability Assessment should be updated to incorporate new climate projections (UKCP18), paying particular attention to how precipitation extremes are incorporated within these uplifts, as per R1.
- **R3:** All routes should consider all vulnerabilities and impacts but apply different emphasis to suit the local primary factors of concern.
- **R4:** The Vulnerability Assessment should consider multi-hazards, and how these may change in the future (albeit noting the limitation of current climate modelling ability in this area).
- **R5:** The Impact Assessment should report on multi-hazards and their collective impact.
- **R6**: Longer-life assets should be stress tested in line with best practice guidance acknowledged the WRCCA plans.
- **R7**: The sensitivity of longer-life assets to increasing slow onset changes and frequency and intensity of extreme events evaluated to the level of high-end low likelihood probability should be considered in future WRCCA plans.
- **R8**: The Vulnerability Assessment should use less conservative estimates of sea level rise, particularly for longer-life assets (see R7).

- **R9**: Network Rail should use adaptation pathways (as acknowledged in the WRCCA plans) as a tool to link actions across different CPs and enable long-term planning for climate change, particularly for longer-life assets.
- **R10**: The WRCCA plans should explain how actions are prioritised for specific CP funding.
- **R11:** Network Rail should consider aligning WRCCA plans with ISO or BS standards for adapting to climate change.
- **R12:** WRCCA plans should have a consistent reporting requirement to identify key interdependencies and how they are being managed.
- **R13:** Network Rail should consider the risks associated with transitioning to a low-carbon economy and its potential implications for weather and climate resilience (*e.g.* See Anglian Water, 2020).
- **R14:** Key terms such as adaptation and resilience should be defined in a glossary.

Secondly, a new enabling environment is required to support the continuing maturity of the WRCCA plans and broader WRCCA strategy. This includes reviewing: (i) the metrics used for weather and climate resilience; (ii) the current processes for monitoring resilience improvements; and (iii) the governance of WRCCA across the organisation.

- **R15:** Network Rail should review the metrics used to measure weather impact.
- **R16:** Network Rail should implement indicators to monitor and evaluate changes to infrastructure resilience (see also R11).
- **R17:** Actions in the WRCCA plan should link to directly to actions in the relevant asset management plans.
- **R18**: The WRCCA plans should be embedded within the new governance structure, which should clearly articulate ownership and accountability for the WRCCA plan actions.
- **R19:** Future WRCCA plans should contain transformational change and tipping points (see also R9).
- **R20:** Future WRCCA plans should consider the governance of hazards that have network wide impacts.

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List of acronyms

ARP	Adaptation Reporting Power
ATP	Adaptation Tipping Points
BGS	British Geological Survey
BSI	British Standards Institution
CaDD	Capacity Diagnosis and Development
CCAP	Climate Change Adaptation Plan
CEAMP	Coastal Estuarine and Asset Management Plan
CP	Control Period
DAPP	Dynamic Adaptive Policy Pathways
Defra	Department for Environment, Food & Rural Affairs
DRAM	Director of Route Asset Management
EA	Environment Agency
ECCA	European Climate Change Adaptation
EEA	European Environment Agency
FTA	Finnish Transport Agency
GB	Great Britain
GIS	Geographic Information System
GPS	Global Positioning System
H++	High ++ (climate change scenario)
LiDAR	Light Detection and Ranging
LNE & EM	London North East & East Midlands
NAP	National Adaptation Plan
NW & C	North West & Central
NRW	Natural Resources Wales
ORR	Office of Rail and Road
PIANC	World Association for Waterborne Transport
PIARC	World Road Association
RCM	Remote Control Monitoring
RCP	Representative Concentration Pathway, a greenhouse gas concentration trajectory adopted by the Intergovernmental Panel on Climate Change. There are four pathways, which the UK Met Office base the current UK Climate Projections on.
SWRRP	South West Rail Resilience Project
TE2100	Thames Estuary 2100
TRaCCA	Tomorrow's Railway and Climate Change Adaptation, RSSB project T1009
TSR	Track speed restriction
UIC	International Union of Railways
UKCP	UK Climate Projection
WRCCA	Weather Resilience and Climate Change Adaptation
WRMP	Water Resources Management Plan

1. Introduction

1.1. Context of Weather Resilience and Climate Change Adaptation (WRCCA) at Network Rail

Weather and longer-term climatic change impacts railway operations causing damage to assets and disruption to railway services (Figure 1). Storms and heavy rainfall events can lead to flooding and landslips (*e.g*. Jaroszweski *et al*., 2015; Dawson *et al*., 2016; Freeborough *et al*., 2016); high winds cause damage to railways assets and blow debris onto the line (*e.g*. Fu and Easton, 2018); and heat is a perennial problem affecting a range of asset types, particularly during high temperatures and heatwaves (*e.g*. Ferranti *et al*., 2016). Multi-hazard events, such as the high temperatures followed by heavy rainfall and lightning during the two-day "Spanish plume" heatwave event of 2018 can be particularly disruptive (Ferranti *et al*., 2018). Weather impacts on the railway network cause £50m-£100m per year due to delays and cancellations, and £200m–£300m a year including broader repairs socio-economic costs (Network Rail, 2017). Flooding generally accounts for the greatest number of delay minutes, but this can vary year-by-year; 2017-18 experienced significant delays due to snow, whereas 2018-19 experienced most delays from heat (Figure 2). Looking to the future, the UK Climate Projection (UKCP) programme, conducted by the Met Office Hadley Centre, projects an increase in the frequency and intensity of heavy rainfall events, wetter, milder winters, and hotter, drier summers, although this will vary regionally and annually (Met Office, 2019). There will also be changes to coastal flood risk associated with sea-level rise.

In order to increase railway resilience to weather impacts and longer-term climate change, Network Rail has developed the Weather Resilience and Climate Change Adaptation (WRCCA) strategy. This is designed in-line with Network Rail's vision of '*Putting passengers first*' by ensuring that Great Britain has 'A *railway that is safe and more resilient to the effects of weather, now and in the future*' (Network Rail, 2017). The WRCCA strategy aims to improve Network Rail's understanding of the impact of current and future climate on their assets and embed weather resilience and climate change adaptation considerations into decision-making. The strategy has four pillars of resilience to develop the evidence base and integrate weather resilience and climate change adaptation into operational and strategic "business as usual" (Figure 3). As part of this process, WRCCA plans (2019-2024; Control Period (CP) 6) were developed for the eight different routes to understand on a regional level the impact of current and future weather. These build on previous WRCCA plans developed for CP5, and on previous work undertaken by the Tomorrow's Railway and Climate Change Adaptation (TRaCCA) project (RSSB, 2015).

Figure 1: Impact of weather on Network Rail Assets (source: Network Rail).

In 2020, Network Rail released a new Environmental Sustainability Strategy that has updated the climate change adaptation strategic ambitions within the organisation (Network Rail, 2020). The overarching WRCCA strategy will be updated in light of the new Environmental Sustainability Strategy, and also a new operational weather resilience/seasonal management strategy which is in development.

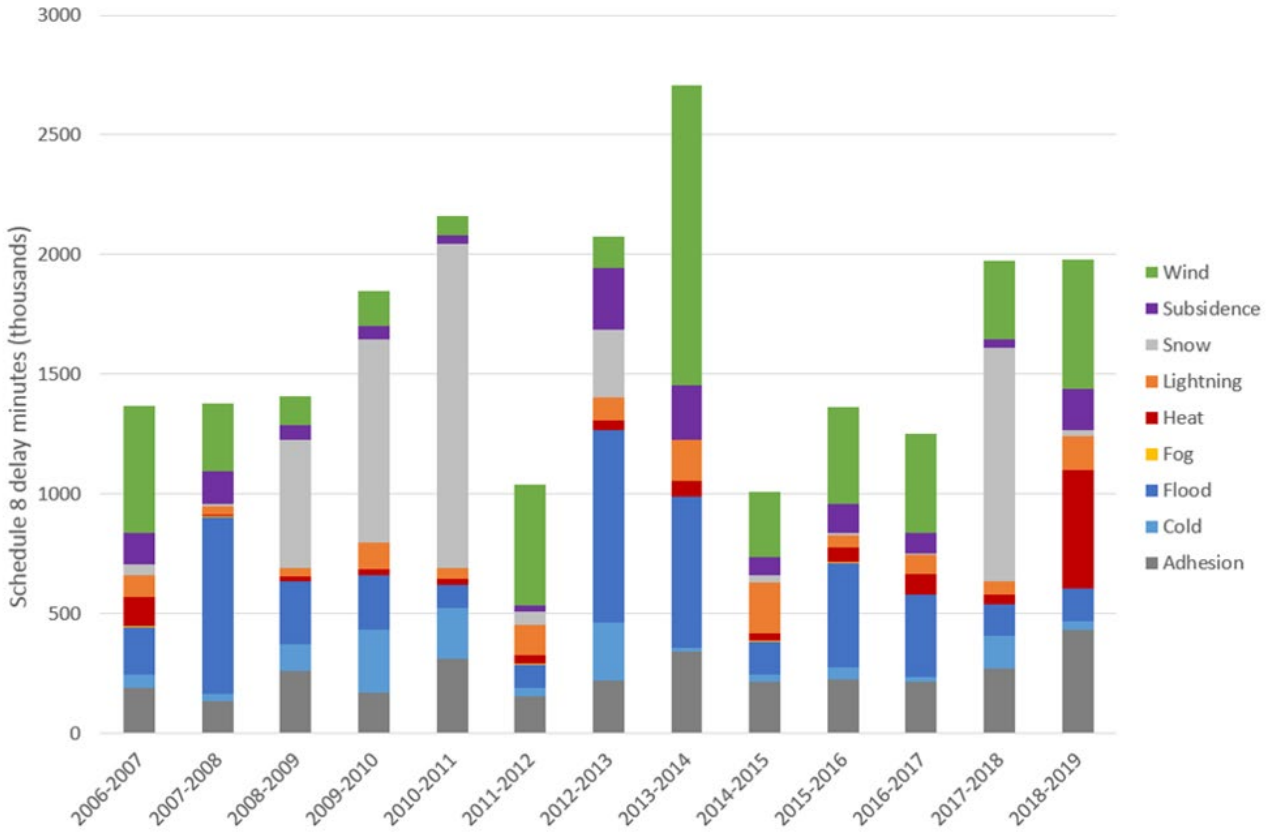

Figure 2: Delays associated with different weather types (source: Network Rail, 2017)

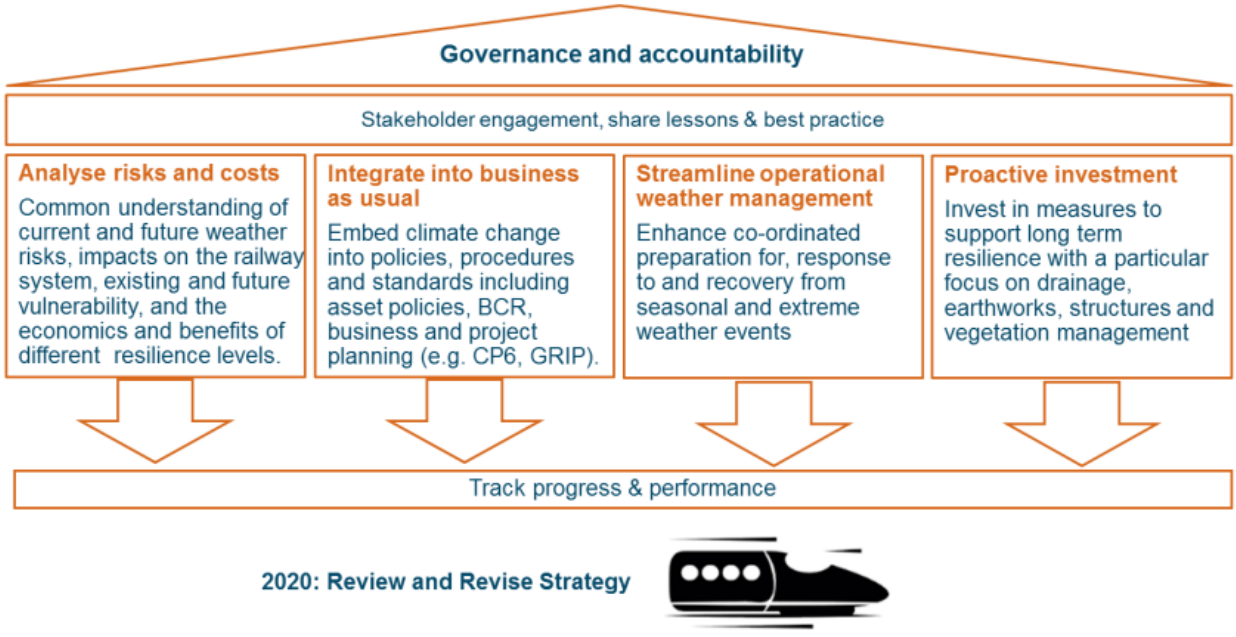

Figure 3: The four pillars of resilience that describe the WRCCA strategy at Network Rail (Network Rail, 2017).

Network Rail also participate in the Adaptation Reporting Power (ARP) process mandated by the 2008 Climate Change Act. This requires infrastructure operators to understand the impact of weather and future climate on their assets and take appropriate action to adapt to climate change. In 2015 Network Rail produced their Second Climate Change Adaptation Report (Network Rail, 2015), and drafting for the third adaptation report, due in 2021, is underway.

1.2. Report objective and scope

Weather resilience and climate change adaptation is one of the key themes for the next regulatory Periodic Review at the Office of Rail and Road (ORR). To support this, this report examines the recent WRCCA plans produced by Network Rail to improve ORR's understanding of the planning process at regional level and identify opportunities for improvement looking forward to CP7. This is a developing area for ORR, and assurance activities in this area are led by the Asset Management team within Railway Planning and Performance directorate. Documents, such as the new Environmental Sustainability Strategy or other developing strategies are beyond the scope of this report. Additionally, as the Network Rail WRCCA plans were produced using the former Route structure, *i.e.* 8 Routes/regions, the findings in this report use this nomenclature.

This report initially provides an overview of international best practice in this area, including providing an overview of ISO 14090, the international standard on Adaptation to Climate Change (Section 2). Section 3 reviews the eight WRCCA plans; Section 4 evaluates the maturity of the plans and provides recommendations for CP7 planning and longer-term resilience. This review is guided by the principles in ISO14090 Adaptation to Climate Change and ISO 55000 Asset Management, but is not an assessment of the adherence of WRCCA plans to these standards.

2. Overview of best practice

2.1. Examples of good practice in the rail sector

In 2017, the International Union of Railways (UIC) commissioned the Rail Adapt project, which gave an overview of existing good practice in weather resilience and climate change adaptation to develop a climate change adaptation framework for use by the sector (Figure 4). The project worked with global stakeholders from the transport, particularly rail, sector to understand current approaches to weather resilience and climate adaptation. The project outcomes, including several case studies of good practice are provided in the Rail Adapt report (Quinn *et al*., 2017; 2018). Pertinent case studies from the Rail Adapt project are summarised in Table 1, however it is unclear to what extent each of these case studies has made the railway organisation and its infrastructure resilient to weather and climate as there is no ongoing evaluation since the project finished in 2017. Other examples of climate change adaptation from the rail sector are provided in the European Union Climate Adapt Portal (Table 1), including the 2014 Network Rail WRCCA plans which feature as a case study on implementing climate change allowance in drainage standards (EU Climate Adapt Portal; Network Rail). Again, each of these case studies represents a snapshot in time, without any reporting of longer-term evaluation, and it is therefore unclear to what extent each of these case studies has increased the resilience of the railway organisation and its infrastructure to weather and climate.

From an organisational perspective, the Rail Adapt report also provides four key conditions for railways to be considered as climate-adapted (after Quinn *et al*., 2017):

- to be operated by organisations which are themselves adaptive, and embed the capacity for adaptation in all their functions, not just asset management;

- to comprehend the range of current and future weather conditions affecting the railway, and have operational and management strategies in place enabling them to respond to weather challenges;
- to comprehend how climate change may affect the range of operating conditions over time, and evolving its operating and management strategies at least at the same rate as the climate affecting it; and
- to adapt to climate change as part of the business as usual scenario, so that the cost of adaptation has only marginal impact on financial performance.

The Rail Adapt framework is based on the experiences of transport administrations, such as the Swedish Transport Administration (Trafikverket; road, rail, shipping and aviation) and the Finnish Transport Agency (FTA; rail, road and maritime) and is compatible with frameworks produced for other sectors, such as the World Association for Waterborne Transport (PIANC) Infrastructure guidance to ports and World Road Association (PIARC). The Rail Adapt report does not identify any other railway organisations with WRCCA plans comparable to those produced by Network Rail.

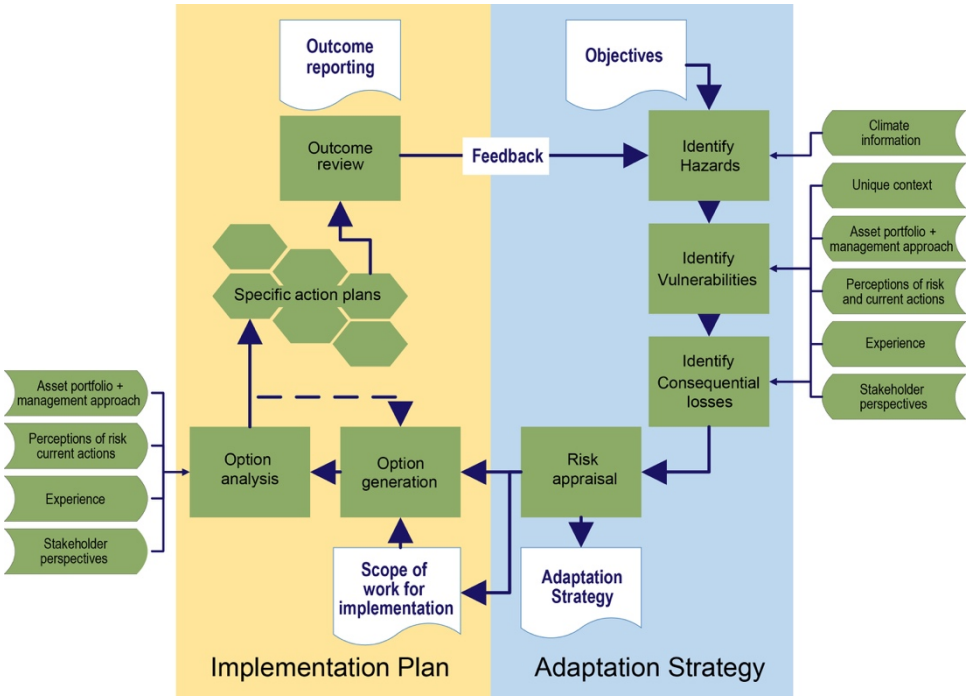

Figure 4: The Rail Adapt framework for climate ready transport infrastructure composed of an adaptation strategy and implementation plan (From Quinn *et al*., 2018).

Table 1: Examples of good practice in weather resilience and climate adaptation from the railway sector from the Rail Adapt Report (Quinn *et al*., 2017) and the EU Climate Adapt Portal.

Case Study	Details
Building railway transport resilience to Alpine hazards in Austria (Climate Adapt Case Study)	Railway lines often run along steep alpine topography and are vulnerable to flooding and other hazards such as avalanches and landslides. Structural measures and a bespoke early warning system that combines meteorological and railway expertise to provide precision forecasts of extreme weather reduce current and future related climate hazards.
TRaCCA (Tomorrow's Railway and Climate Change Adaptation (T925/T1009)	This UK project reviewed the knowledge gap related to climate adaptation and the rail industry, and improved knowledge of climate change hazards and vulnerabilities (2013-15)
Capitol Corridor intercity passenger rail route, San Francisco, USA	As part of the Adapting to Rising Tides project, the Capitol Corridor Joint Powers Authority conducted a vulnerability assessment for sea-level rise along the route.
MOWE-IT	This project identified best practices and developed methodologies to assist transport operators (road, rail, maritime and combined) to mitigate the impact of natural hazards and extreme weather on performance.
Integrating adaptation in the design of the metro of Copenhagen (Climate Adapt Case Study)	The metro is impacted by heavy rainfall, storm surges and storms, and so sea-level rise and the 2,000-year flood event has been used to determine the highest water level for each station.
Adaptation of French standards for design, maintenance and operation of transport infrastructures (Climate Adapt Case Study)	The Ministry of Ecology, Sustainable Development and Energy requested transport infrastructure and systems are adapted to changes in climate up to 2100. Following the review, the standards were updated to ensure long-life infrastructure are resilient to changes in climate.

European experiences:

During the course of this study, our contacts in the European railway community were canvassed for information and reports on weather resilience and climate change adaptation. Two railway administrations, ÖBB-Infrastruktur (Austria) and PKP (Poland) advised that studies are under way. ÖBB-Infrastruktur is working on a climate change adaptation plan for Austrian Federal Railways covering natural hazard management and vegetation control together with the Austrian Meteorological Service and the University of Applied Life Sciences in Vienna. First results in are expected in the autumn of 2021. PKP adopted its infrastructure adaptation plan in June 2019 and sent the authors a web link to the plan. The plan, in the Polish language, is some 60 pages long. A translation of the plan suggests it is a high-level document offering direction and sets a target date of 2030 for adaptation measures. Reference is made to projections using an RCP8.5 scenario and how the greatest sensitivities for Poland's railways are to rainfall-induced events (extreme [river] flows, floods from rivers, sea, sudden/ urban floods, landslides) and storms (lightning strikes) as well as strong winds. Lower sensitivity occurs from low temperatures and snowfall events, as well as high temperatures (including fires) and fog. PKP states that the lower sensitivities to the effects of snow is because of good preparation to respond to the threat and the occurrence of milder winters in recent years. In common with many railway administrations, weather-related problems are a major factor = PKP states how 50% of the duration of disruptions are related to weather factors.

In 2014, the European Environment Agency (EEA, 2014) published a report on the challenges and options across transport modes and stakeholders on climate change adaptation. It refers to some specific European railway operators' approaches to adaptation planning and what actions have been taken. SNCF (France) and Deutsche Bahn (Germany) approach adaptation at a holistic level. SNCF's study phase of their strategy focused on spatial and temporal climate impacts and vulnerabilities, adaptation prioritisation, and assessment of options with overall strategy. Outcomes from the project include developing a regionalised map of climate vulnerabilities based on 30-year forecasts; and updating construction and maintenance standards. Vulnerability assessments are undertaken annually since 2016 and business continuity plans are

in development for the whole of France (SNCF, 2018). The holistic network perspective has been maintained in current/recent research projects in order to meet the objective of designing a long-term action plan for infrastructure (SNCF, 2021). Deutsche Bahn outlines a high-level strategy for climate change adaptation including: expanding vegetation management; resilient signalling equipment; intelligent vehicle technology; and structural protection in risk areas (Deutsche Bahn 2018; 2020). The outcomes of their adaptation plan are as a result of an impact assessment study by the Potsdam Institute for Climate Impact Research. Deutsche Bahn are engaged in a number of stakeholder processes for wider national adaptation plans, which have in turn influenced operational plans for extreme weather events across DB-Netz who are responsible for the rail infrastructure (EEA, 2014).

2.2. Best practice from other infrastructure sectors

Globally, there are several examples of good practice in weather resilience and climate adaptation from transport organisations and the wider infrastructure sector. Global examples include the 100 Resilient Cities Programme (2013-2019) that provided financial and technical support to increase resilience within cities. The Programme features several examples of best practice to increase resilience to climate change and coastal flooding, brought together in the Resilient Cities Network. The European Union Climate Change Adaptation strategy requires infrastructure operators to undertake resilience assessments as a condition of receiving funding from the European Regional Development Fund and Cohesion Fund. For example, in Slovakia, climate change risks and vulnerabilities were considered in the modernisation of a key passenger and freight railway corridor (Table 1). This example and others are shared in the EU Climate-Adapt portal which features more than 100 case studies of adaptation from across Europe EU Climate Adapt Portal.

From the transport sector, PIARC and PIANC both developed similar frameworks or steps for their members to adapt to climate change. PIARC propose (i) identifying scope, variables, risks and data; (ii) assessing and prioritising risk; (iii) developing and selecting adaptation options; and, (iv) integrating outcomes of (i)-(iii) into decision making (Toplis *et al*., 2015). PIANC propose (i) understanding the impact of climate change on assets, operations systems and identifying who needs to be involved; (ii) identifying the climate information required; (iii) assessing the risk to waterborne transport assets; and, (iv) presenting a portfolio of potential measures (structural, operational, institutional) to be considered when developing an adaptation pathway (PIANC, 2020).

With the UK, the ARP process, mandated by the 2008 Climate Change Act, has led to all major infrastructure organisations developing weather resilience and climate adaptation policies or plans. Second round reports were published around 2015, and are available from gov.uk. Organisations, including Network Rail are currently preparing their third round reports due for completion by the end of 2021. Anglian Water have recently published their third report; this includes many aspects of good practice such as a detailed risk assessment, the use of adaptive pathways, an examination of cross-cutting risks and interdependencies, and consideration of the risks of transitioning to a low carbon economy (Anglian Water, 2020). An example of a cross-cutting risk in the transport sector is potentially an electrification programme in order to reduce greenhouse-gas emissions. Track-lowering can be utilised to gain clearances under over-bridges. However this technique may result in waterlogging and flood hazards, which will be exacerbated through climate change.

Several good practice examples use an adaptation pathways approach to climate adaptation. Adaptation pathways are a series of interlinked and flexible options for adaptation that combine short-term objectives with longer-term actions for a range of climate scenarios. Examples of adaptation pathways adopted by professional practice include:

- **Thames Estuary**; the Thames Estuary 2100 (TE2100) project pioneered the use of adaptation pathways for coastal flood management to address flood risk in London and the Thames Estuary until 2100. There

are several options for adaptation dependent on sea-level rise, and projections include high-end low probability climate change as a "worst-case" scenario (*e.g*. Reeder and Ranger, 2011; Ranger *et al*., 2013)

- **Dutch Delta Programme**; is a collaboration between national, regional and municipal governments, and water boards to improve flood risk management and reduce the vulnerability of water supply in Netherlands. It uses Dynamic Adaptive Policy Pathways (DAPP) and Adaptation Tipping Points (ATP) (Kwadijk, *et al*., 2010; Hasnoot *et al*., 2013; Hasnoot *et al*., 2019).
- **Thames Water**; their 2019 Water Resources Management Plan (WRMP, Thames Water 2019a; 2019b) considers future water resources until 2100, including measures to address forecasted supply demand deficits in the region, and increase resilience to severe drought. The WRMP includes an adaptation pathway to secure resilience to a 1 in 200-year drought event before 2030, and consider options for strategic water resource management in the long-term (Thames Water, 2019a).

2.3. BS EN ISO 14090: 2019 Adaptation to climate change – Principles, requirements and guidelines

'BS EN ISO 14090: 2019 Adaptation to climate change – Principles, requirements and guidelines' is the formal UK title for ISO 14090. This standard describes principles, requirements and guidelines for adaptation to climate change. These include integrating adaptation within or across organisations. The standard helps organisations to identify and understand impacts and uncertainties and how these can be used to inform decisions; it helps them to report adaptation actions as well. The standard can be used by any organisation whose activities, products and services might be at risk from, or in some cases able to take advantage of, climate change.

ISO 14090 aims to help organisations prioritise and develop effective, efficient and deliverable adaptation plans tailored to the specific climate challenges they face. The approach enables organisations to consider adaptation when designing and implementing policies, strategies, plans, and actions. It sets out a consistent, structured and pragmatic approach to preventing or minimising the harm that climate change could cause.

To ensure choice and flexibility, the content of the standard is pitched at a high-level, allowing activities to be tailored to the needs of the organisation. The purposely non-linear nature of the standard's approach allows organisations to adopt its structure no matter what stage they are at in their adaptation activities - from those just starting out, to those already engaged in adaptation, to those choosing to lead the way. The application of ISO 14090 is intended to be performed alongside other organisational priorities. This includes carrying out all climate change adaptation activities in parallel with, or integrated with, climate change mitigation activities and other sustainability priorities.

Furthermore, application of this document can assist in demonstrating to stakeholders that an organisation's approach to climate change adaptation is credible. This document can also be of relevance to individuals and organisations involved in purchasing, investment and insurance when seeking to understand another organisation's climate change adaptation. It is designed to help organizations develop measures and report on adaptation activity in a verifiable way. The structure of ISO 14090 covers:

- Pre-planning;
- Assessing impacts including opportunities;
- Adaptation planning;
- Implementation;
- Monitoring and evaluation;
- Reporting and communication.

Note, a longer version of this text is available from a British Standards Institution (BSI) article introducing the new standard.

3. Review

Questions 1-19 (excluding 14) were answered using the methodology outlined in Appendix One.

3.1. Terminology and scope

Q1: Are resilience and adaptation related terms clearly defined and used consistently across the regions?

The use of key words, including adaptation, resilience and other related terms such as impact was examined across the eight WRCCA plans. The plans provide no specific definition of these key words, nor is there a glossary. Although these terms may be explained in detail in other documents, such as the WRCCA strategy, ideally they should be defined in the WRCCA plans to aid understanding. From the WRCCA plans we infer resilience to be closely linked to operational performance, *i.e*. reducing the number of delay minutes associated with different weather types, by reducing the risk and particularly the impact of these hazards, now and in the future.

The usage of key words is broadly consistent, as is their distribution across the individual documents. Several of the sections of text are generic across all documents (see Q2), and here the key words are used almost identically. In those sections of the text, which are specific to the individual routes, "adaptation" is rarely used. "Resilience" is used more frequently within the route-specific sections, and is broadly consistent. For example:

- *'At locations where drainage assets on earthworks are assessed as being under-capacity, a systematic risk-based programme of refurbishment and renewal will bring a gradual improvement in resilience to the impacts of flood water*'. (NW & C, p.35);
- *'Resilience to washouts will also need to be improved with risks from increases in short intense storms'*. (Anglia, p.32);
- *'In recognition of the potential risks that sea-level rise will bring to connectivity West of Exeter, works are ongoing to improve resilience at Dawlish and Teignmouth'*. (Western, p.41);
- *'Creating resilience on current building assets is a key factor to creating and keeping Wales Route resilient to climate change across Control Periods*' - in this example the use of resilience is less clear (Wales, p.25).

Q2: What is the degree of consistency between the scope and components of the WRCCA plans?

All WRCCA plans have the same key sections, namely; Director of Engineering and Asset Management Statement, Executive Summary, Introduction, Route WRCCA Plan, Route vulnerability assessment, Route impact assessment, Region WRCCA actions, Management and Review. Table 2 provides a quantitative overview of key elements of the WRCCA plans. On average, the reports were 47 pages in length; although the Western WRCCA plan was substantially longer (72 pages), with the longest WRCCA plan section and impact assessment (Table 2).

All WRCCA plans have very similar or identical information in certain sections and similarity software calculates approximately 30% similarity in text across all documents. Almost identical sections include:

- The Introduction section, which embeds Route specific information such as weather attributed delay minutes (*e.g*. Figure 3) within generic (*i.e.* identical across all WRCCA plans) information on observed climate change (*e.g*. Figures 4,5) and future climate change projections (Figures 6,7,8);

- The opening section of the Route level WRCCA plan that outlines the company vision and principles in respect to weather impacts now and in the future.
- The opening one or two (depending on Figure size) pages of the Vulnerability Assessment, including Figure 11 (occasionally listed as Figure 12) that describes network-wide vulnerability and approach;
- The first paragraph of the Route Impact Assessment outlining the performance impacts approach;
- The opening statements of the WRCCA Route actions and a list of National Adaptation Programme (NAP) actions, which are the same for all Routes in England, but different for Scotland and Wales.
- The Management and Review Section (although the subtitle Governance & Review is changed to Corporate Management and Review for Wales and Scotland).

	Anglia	LNE & EM	NW & C	Scotland	SE	Wales	Wessex	Western
Release Date	Sep 20 (v1)	Oct 20 (v1)	May 20 (v2)	Sep 20 (v1)	May 20 (v3)	May 20 (v3)	Oct 20 (v1)	Sep 20 (v1)
Page Count (total)	43	52	48	42	39	36	40	72
WRCCA plan*	2	2	2	1	2	1	1	7
Vulnerability Assessment*	8	14	12	16	10	9	15	9
Impact Assessment*	16	16	16	7	12	8	7	24
WRCCA actions*	5	5	4	5	2	4	4	1

Table 2: A comparison of key elements of the WRCCA plans. *refers to the page count of several key sections of the WRCCA plans.

The remainder of the report, in particular the vulnerability assessment, the impact assessment, and the WRCCA actions are specific to each Route, but follow a standardised approach.

- In the vulnerability assessment, the weather vulnerability of the Route is described, then several future climate change projections, predominantly in terms of the UKCP18 Representative Concentration Pathways (RCPs) are provided. These comprise: mean daily maximum temperature change and mean daily minimum temp change for 2030s, 2050s and 2070s (RCP6.0, 90th percentile); mean daily precipitation change, for the 2030s, 2050s and 2070s (RCP6.0, 50th percentile with the 10th and 90th given as a range); river flow uplifts produced by the Environment Agency (EA) based on the UKCP09 Medium Emissions scenario for 2050s and 2080s; and, sea-level rise for the 2030s, 2050s and 2070s (RCP4.5 95th percentile).
- The impact assessment considers the impact of weather (adhesion, cold, flood, fog, heat, lightning, snow, subsidence, wind) on Route performance within the context of climate change projections, then gives a priority of high, medium and low to the future risk from each weather impact (shown in Table 2 of each Route WRCCA plan). The reasoning for each level or risk is not given.
- The impact assessment then provides detailed impact assessments for heat, cold and snow, flooding and sea-level rise, wind, lightning and adhesion for different asset groups.
- The WRCCA plan action section reviews the progress on Route actions from CP5, lists funded Route actions for CP6, lists non-funded high-priority Route actions for CP6.

Within this standardised approach, there are differences in the focus between Routes. In particular:

- The Western WRCCA plan is significantly longer, with greater detail on the WRCCA actions and costs for CP6. It also describes adaptation pathways planning on the Somerset levels;

- The Scotland WRCCA plan provides cross-references actions with Climate Ready Scotland policy in greater detail than for the England Routes with any corresponding national or regional policies;
- The Wales WRCCA plan includes a section on climate mitigation, which is not present in the other plans.

Q3: At what level is resilience targeted (strategic, asset performance, operational)?

In the broadest sense, resilience to weather impacts and longer-term climate change is targeted at the performance of the railway network. '*The costs of weather attributed Schedule 8 and 4 payments and the wider socio-economic impacts of rail disruption on the UK justify continued investments to increase current weather resilience'* (Introduction text in the WRCCA plans). Delay minutes and Schedule 8 costs attributed to weather impact are provided in the Introduction and Impact Assessment and are used to prioritise weather impacts for action into high/medium/low (Table 2 of the WRCCA plans), although the methodology for this ranking is not provided. The impact of weather as derived from Schedule 8 delay costs was disseminated to asset function teams and the Routes for use in asset maintenance and investment planning.

At Route level, actions to increase resilience are linked to improving asset performance, operational recovery and response, or longer-term strategy. For example, to improve asset performance, there may be a programme of repair and or renewal. The North West and Central (NW & C) Route are undertaking systematic refurbishment of their earthworks to increase flood resilience, Anglia Route are renewing assets to increase resilience to heat, NW & C are prioritising deteriorating assets for maintenance. Action related to operational recovery and response include condition monitoring of track to indicate when Temporary Speed Restrictions are needed (*e.g*. Anglia), or when there are problems with drainage (*e.g.* LNE & EM) or to alert of a landslip (*e.g.* Wessex). The impact assessment also stated many strategic actions that would be suitable to improve long-term resilience, such as upgrading builds to operate more efficiently in a different climate (*e.g*. Wessex), or more frequent and more robust vegetation management to address anticipated increases in the growing season (*e.g.* LNE & EM). These longer-term actions are not generally listed in the Route WRCCA action tables.

Q4: Is there reference to supplementary plans such as flood plans, high winds plan?

All WRCCA plans referred to other plans, programmes and strategies within the text, and in some of the Action Plans. These documents were not formally cited as references, and it is not always clear whether these are Routes specific plans, or a broader plan, that sits alongside the WRCCA plans. In more detail:

- Vegetation management programmes and plans are mentioned in most WRCCA plans excluding South East and Wales with respect to managing tree fall and adhesion risk; it is unclear whether these are national or Route level plans, or how closely weather and climate resilience are embedded within these plans;
- Drainage Management plans are referred to in order to increase flood resilience; these are mentioned less than vegetation management plans, and are assumed to be Route level documents, but their scope and linkage with the WRCCA plans is unclear;
- Some Routes (*e.g*. Anglia) refer to Route level coastal management plans and strategies, or Earthworks Management Plans but their linkage to the WRCCA plans is unclear;
- "High winds plan" are not mentioned in the WRCCA plans. Wind impact is often linked to treefall risk and operational controls, such as track speed restrictions (TSRs) or route closure to traffic, during actual or forecast periods of high winds. It is known that these operational plans differ between routes but linkage to the WRCCA plans is unclear.

3.2. Strategic Alignment and Integration

Q5: Do plans align to relevant policies and strategies, and is there line of sight to implementation?

All WRCCA plans refer in some way to CP6 strategic business planning. The more comprehensive plans (such as Western's) reference "Key Route Strategies", "Network Rail standard specifications", and Network Rail's "Environment and Social Standard". All (but Scotland's owing to different legislative requirements) refer to the Department for Environment, Food & Rural Affairs' (Defra) national climate change guidance and the importance of the NAP.

Box1: "Line of sight"

Guidance on the implementation of ISO 55001 is given in ISO 55002:2018 Asset management — Management systems — Guidelines for the application of ISO 55001. This guidance explains how the concept of "line of sight" is of key importance in designing an asset management system; '[…] line of sight from context of the organization to asset management policy to the Strategic Asset Management Plan to asset management plans to operation'. Simplistically, this means the systems should offer visibility of all asset management activities from the top of Network Rail to the bottom – for example from the CEO down to track inspector.

References to policies and strategies does not imply alignment, and whilst many Network Rail policies, procedures, projects and standards are addressed to embed climate change specifications there is little reference to asset policies specifically, making it difficult to conclude that plans are aligned *e.g.* the prioritisation of climate risks shown in the Tables of actions within each WRCCA plan do not seem to have a direct relationship with the selection of actions. Also, the commitment made to managing long-term climate risks is not reflected in the selection of actions which are current focused. The selection of actions tends to be more closely linked to current performance metrics. This suggests a disconnect between metrics, policy and strategy. Equally, some plans recognise that the Route does not yet have the adaptive capacity for more adaptive action setting. They do anticipate that this will change for future CPs. Some include those measures in their action plans.

"Line of sight to implementation" is not specifically addressed but each plan mentions how the Route WRCCA plans are owned by the respective Director of Route Asset Management (DRAM). Reporting on the implementation of the plans *by implication* seems to be a task of the DRAM, with ORR referred to as "monitoring each Route's progress". It could be inferred, therefore, that "line of sight" is addressed. As a concept "line of sight" is integral to the best practice asset management outlined in ISO 55001:2014 Asset management - Management systems- Requirements – see Box 1. As Network Rail aspires to following asset management best practice, and as the DRAM is said to be the owner of the WRCCA plan, this seems good but could have been directly addressed.

Statements like '*Effective governance of the wider WRCCA programme including Route WRCCA Plans will be embedded within the new governance structure'* are not backed up with evidence of what and how this will happen after an impending reorganisation has been implemented.

Box 2: ISO 14090: Adaptation best practice and policies, strategies and plans

ISO 14090, requires the identification of policies that affect adaptation planning. Statements are recommended on how adaptation strategies, plans and policies relate to other internal and external policies and strategies, and ISO 14090 specifically mentions "national adaptation plans", the UNFCCC Paris Agreement and UN Sustainable Development Goals

Statements in each plan were given on "high level management, review and reporting", viz: *'Routes will provide updates on implementation of their WRCCA Plans to ORR and the central WRCCA Team twice a year (at the end of Periods 6 and 13). A report combining progress from all Routes will be presented to the National Asset Management Review Group and Quality, Health, Safety and Environment Integration Group (or future equivalents) twice a year. Progress in implementing milestones will be included in regular WRCCA reviews by the Network Rail Executive Leadership Team and the National Safety, Health and Environment Periodic Report (or future equivalent). Route WRCCA Plans form a key control in managing Network Rail's Enterprise Risk relating to weather related impacts on the railway which is managed through Route and National level Business Assurance Committees (or future equivalent).'*

See Box 2 for information on what constitutes "best practice adaptation planning" in the context of policies, strategies and plans.

Box 3: ISO 14090: Adaptation best practice and adaptation measures

Best practice climate adaptation measures can include "soft" and "hard" measures and a mix of both; "soft" measures can include adaptive capacity building, behavioural change, embedding climate change adaptation and resilience themes into Network Rail's policies, strategies and plans. Training, flood forecasting systems, and standards are also examples of soft measures.

Hard adaptation measures can be categorised as "grey" or "green". Grey measures are commonly traditional engineered methods such as embanked flood defences and sea walls, and cooling buildings and urban areas by good design. Green measures typically are those working with nature; making space for floodwater, using water features and parkland for cooling cities, and slowing flood flows in upland catchments through "re-wilding" of land and forestry.

Q6: How are climate adaptation measures incorporated into the asset management processes and organisational business processes?

All plans alluded to the good practices of embedding resilience and climate change measures, *'Including current and future weather impacts in our risk analysis and investment decision making and embedding climate change specification into policies, procedures and standards'* (in all Route WRCCA Plan sections), and Central team support to this is mentioned. See Box 3 for best practice in the context of adaptation measures.

Concerning longer-term climate adaptation some good points were noted in all plans – Wales, for instance incorporating climate adaptation into asset management/ organisational business processes, by establishing a coastal and estuarine asset management strategy to identify future weather risks and to develop '*a plan to mitigate against sea-level rise'* (p.12). Each plan contained statements that *'Routes will provide updates on implementation of their WRCCA Plans to ORR and the central WRCCA Team twice a year (at the end of Periods 6 and 13)'* (in all Management and Review sections) and *'A report combining progress from all Routes will be presented to the National Asset Management Review Group and Quality, Health, Safety and Environment Integration Group (or future equivalents) twice a year'* (in all Management and Review sections).

However, whilst these updates and reports are good in themselves, it could be asked, 'how are these plans set up for implementation, monitoring and evaluating?' Best practice adaptation planning, as outlined in ISO 14090, requires

implementation plans, indicators and arrangements for monitoring and evaluating progress in achieving adaptation. There was no evidence of such indicators, or detailed processes to monitor and evaluate the effectiveness of activities related to resilience and adaptation.

Q7: Is climate vulnerability assessment integrated with risk management from an organisation risk perspective?

The vulnerability assessment of each WRCCA plan states that the impact of weather as derived from Schedule 8 delay costs was '*disseminated to Network Rail's national asset function teams and the routes for use in asset maintenance and investment planning'*. The Impact Assessments and the WRCCA action plans describe Route specific actions for different assets to improve resilience. However, there is no detail provided on the linkage between the WRCCA plans and other business and asset management plans, or how information in the WRCCA plans feeds into the asset management processes. This need for feedback is another example of where best practice indicators, monitoring and evaluation can help to improve future WRCCA plans.

Asset management best practice (as outlined in the ISO 55000 series Asset Management standards) requires actions to address risks over time and the integration of risk mitigation actions into asset management system processes. Furthermore, corporate principles and aims are alluded to but links to wider, organisational risks are not evident; having these links and risk mitigation actions brought into the asset management system would be a significant improvement.

Q8: Was there stakeholder analysis and involvement in the resilience planning?

'*Working with stakeholders to identify opportunities to enhance our preparation for, response to and recovery from adverse/extreme weather events*' is part of Network Rail's vision for a railway that is safer and more resilient to weather impacts now and, in the future, (all WRCCA plans, ~ page 12). All WRCCA plans note stakeholder engagement, generally with local authorities or the EA to work on shared problems such as flooding. The extent of stakeholder analysis and involvement in resilience planning is not clear from the WRCCA plans. Some WRCCA plans also noted a lack of stakeholder collaboration, for example NW & C*, 'there has been no consideration of such cross-party arrangements in the planning for CP6, but NW&C Region remains an active member of the Cumbrian Strategic Flood Partnership and continues to build strong links with the EA and other relevant statutory bodies*' (p.36). Several WRCCA plans note the lack of authority to manage third party trees on adjacent land, which represent a risk to railway operations.

In all Management and Review sections, NR state the intention *'to engage with the wider rail industry, specifically Train Operating Companies and Freight Operating Companies';* there is no evidence in the WRCCA plans for this, except in the Western plan. The plans did not specify how NR engage with ORR in relation to their 'holding to account' role.

3.3. Adaptation Planning

Q9: Planning horizon – does the plan sufficiently cover immediate actions (in CP6) to manage weather risks and long-term plans for climate adaptation? *(see also Q14)*

The CP6 action plans across all the WRCCA plans have a climate impact assessment which provides a strong foundation for addressing climate changing risk over the life of Network Rail's decisions. The plans are currently strongest at managing current climate (weather) risks. The climate impact assessment recognises where changing climate risk will require different planning. In many cases the routes are applying their expert judgement to begin identifying the implications of those changing risks. These judgements are not

consistently translated into actions yet *e.g.* whilst naming adaptation pathways planning as a way to identify and manage long-term climate risks in current decision making, they have not yet developed their adaptation pathways plans. A number of routes recognise that they do not yet have the capacity to confidently make those judgements. They anticipate this changing in future CPs. As they move towards making those decisions there are some slight improvements that could be made to the impact assessment approach that will be helpful to them. In particular:

- Extending the scenarios used for vulnerability assessments to consider High++ (H++) scenarios that will reveal the low probability and high impact risks that could reshape the decisions we make today *e.g*. the South West Rail Resilience Project (SWRRP) where one of its four activities is taking a relatively progressive approach by designing for resilience to 1.1m of sea-level rise over the next 100 years. However, Defra best practice encourages sensitivity testing up to a H++ scenario of 2m, in line with UKCP18 guidance. Even Defra's high case scenario advises planning up to 1.62m (EA, 2020). Whilst this may not happen, understanding the implications of these high case scenarios can change current decisions that will not be covered by the parameters in the WRCCA plans. In the SWRRP example above, it is also unclear why only one of the 4 activities mentions considering a relatively high case sea-level rise scenario, when all activities are likely to be vulnerable top sea-level rise, and will be increasingly vulnerable to a H++ scenario. This may make future additional measures more difficult and expensive than they need to be if Defra guidelines are followed.

- The UKCP18 climate change data used for the impact assessments details average changes in daily mean precipitation. Generally, it is extreme rainfall that is associated with greatest impacts, and understanding the change in extreme rainfall events rather than change in mean daily rainfall will aid planning for future extreme events.

The conclusion here is that whilst some improvements can be made, the impact assessments that WRCCA plans provide supports effective adaptive decision making.

Other limitations to the WRCCA plans have a larger impact on the resilience of decision making in CP6. These focus on what is done with the analysis that the impact assessment generates. These pathways to even better adaptive decision-making lie in:

- Planning frameworks;
- Metrics;
- Overarch governance linking WRCCA plan analysis to overarching policy and strategy.

Planning frameworks

Whilst WRCCA plan impact assessments take a long-term view of climate risk, that analysis does not yet translate into CP6 WRCCA plan actions. They have a weather hazard perspective to mitigate impacts to their routes. Therefore, there is indication that the approach takes more immediate risk into account as opposed to the longer-term. As stated in Western's WRCCA plan: *'the primary strategic approach adopted in CP6 is to ensure that consideration of weather resilience is incorporated into the remit of all projects is being delivered'* (p.3). Each WRCCA plan's CP6 actions varies in weighting of actions by weather type:

- Anglia: Heavily focused on flooding and subsidence vulnerability;
- London North East & East Midlands (LNE & EM): Mostly focused on temperature (hot and cold weather);
- NW & C: Balance of heat, subsidence, wind and flooding;
- Scotland: Encompasses a larger range of impacts through *"high rainfall"* (landslip/flooding/erosion);
- South East: Focused on generic rain/wind impacts;
- Wales: Mostly focused on flooding and earthworks;

- Wessex: Mostly focused rainfall related to flooding and landslips;
- Western: Covers most vulnerabilities, but CP6 actions are heavy on risk assessments, surveys, investigations, monitoring and data collection.

Similarly, some of the action plans avoid certain vulnerabilities. Heat is a vulnerability not accounted for in multiple WRCCA Route action plans (Anglia, Scotland, South East, Wales, Wessex). The vulnerability assessments of the WRCCA plans address heat as a medium priority to their networks (apart from Western who rank it as high). However, when accounting for Schedule 8 costs, there are instances where heat has been a similar, if not greater cost to the route than where the CP6 actions are focused. For example, the Anglia WRCCA plan intends to invest in flooding and subsidence activities (albeit ranked a high risk), of which 13 years' Schedule 8 costs are an annual average of £0.58m and £0.22m, and heat's is £0.41m. Furthermore, the highest Schedule 8 cost of subsidence on the Anglia route is £0.53m compared to £2.6m for heat. This highlights the difference in thresholds for action/inaction by route according the WRCCA plan vulnerability assessment methodology. In the case of Anglia, there is a strong link between the CP6 actions and the actions and milestones set by the National Adaptation Plan for Network Rail, even though these do not correlate directly to the vulnerabilities identified in Anglia's WRCCA plan. Other routes will have followed different logic.

As for long-term plans for adaptation, these are less clear in the actions plans. However, the WRCCA plans acknowledge the need to work towards it, as mentioned at the start of the Management and Review section in all documents: *'Successfully implementing WRCCA across the whole of Network Rail requires a long-term commitment to the regular review and management of the process at all levels of the business'.* All WRCCA plans also make commitments to undertaking adaptation pathways plans, although they are not yet evident in their WRCCA plans. There are a range of comments and statements across the WRCCA plans that take into account progress beyond CP6 to varying degrees:

- Findings of the Coastal Estuarine and Asset Management Plan (CEAMP) developed in CP5 will be used to determine renewal works for CP7 onwards (Anglia), and such a strategy can support the EA's development of a 100-year estuary strategy (LNE & EM);
- Acknowledging that the current funding for the Vegetation Management Plan means lineside resilience targets will not be met until CP9 (NW & C);
- Participation in a regional scale Adaptation Pathway planning exercise with a Local Authority (Western). In this case, whilst the Route acknowledges their participation, this exercise was led by the Climate Sense team on this assignment. The Route team found it outside their remit at the time to consider the long-term climate impact opportunities presented by the exercise. Network Rail's central team made much more use of the findings;
- As mentioned above, the SWRRP is a particularly outstanding case where long-term scenarios are being factored into planning.

Each WRCCA plan refers to conducting adaptation pathways planning exercises to identify changing future risk and their implications for current decision making. Other than Wessex's involvement in a high-level exercise for the whole of Somerset, this step is not yet evident in the plans. Many of these gaps will begin to be filled when this approach is systematically adopted in WRCCA planning.

Metrics

Amongst the things that keep the Routes focused on current weather impacts are the metrics that are guiding their planning. Metrics do not focus on how future changing climate impacts on the train service that Network Rail supports, even in terms of delay minutes (which are related to timetabled train services). Also,

reporting on metrics of past or future investments do not consider the depreciation of investments with the objective of increasing climate resilience and so it is difficult to know whether the climate resilience objectives of the investment are on track or not. It is also difficult to make assumptions about the impact of adaptation options on future risk to the rail service.

Current metrics are also reported in WRCCA plans to limit the focus of prioritisation of actions. Wales, for example identify the impact of changing flooding on buildings. With an increased risk of fluvial or tidal flooding of 40-240% by 2050, the relatively low impact addressing this risk would have on delay minutes lowered the priority of intervention to address it:

'Something not noted is the non-Schedule 8 delay minute costings, e.g., damage to building assets on the Route due to flooding and/or high winds. Creating resilience on current building assets is a key factor to creating and keeping Wales Route resilient to climate change across Control Periods' (p.25).

The value of different metrics was an issue picked up by the TRaCCA project (RSSB, 2015; see Box 4 below). These insights may be worth revisiting in the light of these findings.

Box 4: TRaCCA Report recommendations on metrics for climate resilient rail

This research is suggesting that a more appropriate measure is the notion of Journey Availability which is a compound function of Infrastructure Availability and Service Availability (Crewed Vehicles). The asset management processes of Great Britain (GB) Railway for infrastructure and vehicles are the activities that will primarily drive Journey Availability and these assets include artefacts, interdependencies, external dependencies and people (skills and behaviours).

Managing performance through Journey Availability would guide the things that need to be measured and reported in relation to the assets, the geo-physical conditions and, critically, the impact of climate change and specific extreme weather events on all parts. Any performance evaluation will therefore necessarily need to be capable of including a significant time horizon.

This would be enabled by the "system of systems" view which could help to determine what information is required at each organisational level and over what time periods in order to generate an effective Journey Availability management strategy. It would help to inform when future interventions will be required for adapting to the effects of climate change. In particular the concept of Journey Availability is not limited to railway transport; development of the concept across all modes of transport would enable an integrated assessment of climate change adaptation

Governance

This issue overlaps with the following question related to systemic thinking. The strong foundation for adaptive thinking provided by the impact assessment leads some WRCCA planners to consider adaptation options. Which option to take can require central policy and strategy decisions *e.g*. the Wales example of the limitations of the Schedule 8 delay minutes metric. Routes are unlikely to be able to change the use of this metric autonomously. It is not clear how Routes are able to feed into a "bottom-up" process to develop strategic resilience, neither is it clear how "top-down" processes feed into Route resilience development, beyond the development of the impact assessment approach. An example is the requirement of the NAP:

'Network Rail's Safety, Technical and Engineering (STE) Horizon Scanning Group will continue to identify, assess and manage external risks to Network Rail throughout their regional Strategic Business Plans for CP6'.

How this horizon scanning does or will feed into Route WRCCA plans is unclear, although the benefits of doing so seem significant.

Q10: Systems thinking and collaboration – is there a cross-asset, cross-sector approach involving collaboration between business units and different organisations?

Each WRCCA plan demonstrates collaboration across teams and organisations, with varying levels of detail. Firstly, there are general statements on the devolved administrations national adaptation plans (England's NAP; Climate Ready Scotland; Wales' CCAP). The Met Office UKCP18 data and other information from the EA

are used to assess future climate risks. The national adaptation plans are referred to within the Action Plan sections with consistency in each WRCCA plan. However, the direct linkages of CP6 actions to these documents can be limited. Each CP6 action plan table near the end of the WRCCA plan documents ends with a column that cross-references, where relevant, the action proposed by the Route to the national adaptation plan policy or objective. These range from a comprehensive and almost complete alignment by Scotland, to one cross-reference by South East. Furthermore, all the WRCCA plans indicate that the outcomes of the WRCCA plans build into the UK Government ARP.

External bodies to Network Rail are frequently referred to in different projects as part of the impact assessments, CP5 reviews and CP6 action plans. There is clear evidence that the Routes have, are, or plan to partner with local authorities and/or county councils on projects such as flood risk (Wessex) or to ensure all parties are aligned with EA goals (LNE & EM). There are also projects with academia in place for MSc and PhD students (Wales; Wessex).

Other sector partnerships from an infrastructure operator perspective are lacking, in comparison. Generic text on interdependencies is mentioned, from the perspective that weather vulnerabilities along with the complexity of assets in both condition and location are overlaid with the interactions of other sectors *e.g*. power, telecoms and water infrastructure. There is no further investigation, such as in the Impact Assessment section to address this, possibly with the exception of Anglia's action to engage with Local Authority highways teams on flood risk management.

Within Network Rail, there are more consistent cross-departmental collaborations. The route WRCCA progress feeds into a central WRCCA team, and the WRCCA plans are monitored by the cross-functional Safety & Sustainable Development team. Furthermore, the Network Rail national asset function teams are informed of the WRCCA outputs, which are used for asset maintenance and investment planning, although it is not necessarily evident in the action plans where such engagement or involvement is practically in place. This is because with the exception of Western, no other action plan table indicates an action lead or accountable person(s).

Q11: Do the WRCCA plans demonstrate evidence-based decision-making using suitable data sources?

There are references to evidence throughout the WRCCA plans, primarily in the vulnerability/impact assessment sections. These sources used in the WRCCA plans can be separated between primary, collected by Network Rail; and secondary, externally to Network Rail. All of the WRCCA plans use primary data, Schedule 8, in costs and delay minutes, and these are regularly referred to in order to quantify vulnerability to the respective route's network. The methodology for the impact assessment according to the WRCCA plans inputs this data into a geographic information system (GIS) to identify high risk locations. However, results of this methodology are not evident within the impact assessments. The exception may be Western, who show maps of impact sites to weather, though it is not clear if these derive from the GIS mentioned.

The vulnerability assessment heavily relies on climate projection data in the UK, mainly UKCP18 which is the most up-to-date set of data available for climate projections. UKCP09 is also referred to for specific parameters no longer available in UKCP18 (river flow uplifts; wind; snow; lightning; fog). The scenario selection for UKCP18 (RCP6.0 90th percentile) is guided by a JBA consulting document mentioned in all WRCCA plans, referenced in the Introduction. This information has enabled Network Rail to prioritise the vulnerabilities across the network, as per the Impact Assessment table.

Two academic references are mentioned across all the WRCCA plans in their introduction: Wang *et al*., (2012) and Parker *et al*., (1992). The data in these references are used to illustrate the long-term trends (general increases) in Mean Central England temperature and high latitude Atlantic storm frequency/intensity. These

references, however, are not relevant to any decision making in the WRCCA plans, other than highlighting the acknowledgement of longer-term climate change.

The WRCCA plans also demonstrate the aspiration to use or create more empirical data for monitoring purposes. The CP5 review and CP6 plan tables address multiple activities to collect more data. Examples include:

- Extending database of sites in critical locations for rail buckle risk in heat (Anglia);
- Improving vegetation management through collecting Wheel Slip Detection and Global Positioning System (GPS) equipment data on new rolling stock for adhesion purposes (LNE & EM);
- Drainage asset data collection to identify missing data and deliver a boundary-to-boundary dataset for more targeted maintenance (NW & C);
- Decision-support tools incorporating Light Detection and Ranging (LiDAR) and railway asset data to identify high consequence locations for tree failures (Scotland);
- Use of an "Earthworks Watch" system using Soil Moisture Deficit and Soil Moisture Index variables to identify when earthslips are more likely (South East);
- Receiving data through MetDesk, Natural Resources Wales (NRW) and EA for fluvial flood warning data (Wales);
- Location specific case study to quantify coastal flooding and erosion risk at Poole Harbour (Wessex);
- Modelling flood risk projections using GIS layers from the likes of the British Geological Survey (BGS) and EA (Western);

The reference to these data across the WRCCA plans is mostly descriptive, and at this stage may not demonstrate their influence in decision-making by the Routes until a later CP.

Q12: Option analyses – are risk magnitude for the vulnerabilities, now and future used for option selection and prioritisation?

The WRCCA plans quantify risk to the vulnerabilities primarily through Schedule 8 costs. This is graphed in their introductions and tabled with prioritisation in the impact assessment tables. However, this information is not reflected in the action plans and there is no evidence of their prioritisation. The weighting of actions in the plans are not necessarily proportionate to the vulnerability prioritisations. Adoption of guidance from Defra and UKCP18 to include sensitivity tests to H++ scenarios and back casting implications for current decisions via an adaptation pathways planning process is likely to change options analysis and prioritisation (please also see response to Q9 above).

Q13: Does the plan cover maintenance and renewals planning for critical assets, and operational mitigation?

The action plan table in all WRCCA plans includes renewal plans for a range of assets. There is generic text across them all in the Route WRCCA Plan sections:

'Adapting at construction and at asset renewal, designing schemes to be resilient in the most cost-effective manner to and/or with passive provision passive provision for future weather conditions'.

However, the approach to asset renewal is not consistent. There is primarily a reference to earthworks and/or drainage renewals (Anglia, LNE & EM, NW & C Scotland, Wessex). They are typically general actions in targeted locations, but Wessex also refers to a Geotechnical Renewal and Refurbishment programme, which is not location specific. Some other asset renewal plans cover track (LNE & EM, NW & C, Western), signalling (LNE & EM, NW & C) and OLE components (LNE & EM). Furthermore, there is no distinction of asset criticality, so it is not clear whether renewals actions by each WRCCA plan are based on any prioritisation by Route.

Operational mitigation is interpreted as actions in the CP6 plan that are led/affected by operational teams across the routes, which reduce the impacts of vulnerabilities to weather and climate. Across the WRCCA plans, this is heavily focused on vegetation management plans and remote condition monitoring (RCM) installation activities. The work undertaken by these teams related to weather resilience is not explicit and there is no linkage between the WRCCA plans and actions within other plans, such as vegetation management. There is also reference to reducing risk to staff from extreme weather in the South East WRCCA plans, something not accounted for by other routes. Changing weather extremes (*e.g*. an increased frequency of hot days) may require maintenance strategies to adapt to reduce risk to staff.

3.4. Action Plans and Best Practices

Q14: What is the gap against best practices from other sectors, Industry and Government guidance?

The concept of "best" practices should be understood to be good practices that currently support and encourage appropriate outcomes, not a fixed set of prescribed behaviours that are instantly transferrable from one industry sector to another. Therefore, in looking at other sectors and their approaches to adaptation planning we cannot immediately conclude that any differences are "better" or "worse" than those being used in the Rail sector as the application and policy framework may argue for a different approach being appropriate. That said, there are clear differences which may be worthy of appropriate consideration.

UK Government approaches

The UK NAP and Climate Change Risk Assessment clearly form the context for Network Rail adaptation activities including the WRCCA plans. Whilst these do not specify exactly how organisations undertake assessments of vulnerability or resilience there are recommendations to guide organisations based on the best available evidence and emerging practice across sectors. A key example of this would be the recommendations and approaches published by the EA for climate change allowances in flood risk assessment including figures for extreme climate change scenarios, known as H++ allowances.

The EA currently use a variety of climate scenarios when they provide advice on flood risk assessments and strategic flood risk assessments, depending on the context and period over which the assessment is required. Long-life and critical infrastructure would therefore typically be expected to be assessed against higher allowances for climate change. For example, the EA currently use an RCP8.5 scenario expecting +4°C mean atmospheric warming for all costal planning and this scenario is typically used for "stress testing" adaptation

plans. In line with this the WRCCA plans refer, in the introduction, to JBA consulting recommendations to use RCP8.5 (90th percentile) scenario values in sensitivity tests on asset vulnerability beyond 2050. However, it is not clear if this is part of current adaptation planning at Network Rail, as there is no further mention of this in the WRCCA plans.

Industry

The water industry and energy sector are examples of other industry areas that have well developed adaptation strategies. The concept of Adaptation Pathways is one that has gained traction within such sectors and would be relevant to the Rail sector given the common factors of long-life (and historical legacy of) linear infrastructure, and major coastal and flooding concerns. Adaptation pathways enable a phased approach to adaptation over time by considering and planning for what future steps may be required, even if the timing of these is not known. For example, the foundations of a coastal structure may be constructed to a longer design-life and capacity than initially necessary to enable additional height to be added to the structure at some future time when sea-level and wave action pass a threshold of increased risk, assessed by maintenance inspections, condition monitoring and regular risk reassessment. The flexibility that this gives, in both future responses and timing, about future resilience thus outweigh the marginal costs at the initial stage, especially compared to an equivalent future complete rebuilding cost at a higher specification. This approach was pioneered in the TE2100 project but has been applied to many other infrastructure projects since.

Such an approach is founded in an understanding of the range of scenario predictions and this implies a clear inclusion of what are currently considered "extreme" scenarios, such as H++ for time period up to and beyond 2100. As mentioned above the WCRRA documents demonstrate an awareness that such an approach is possible, but it is only discussed further in one WRCCA action plan (Western).

Other guidance

Within the infrastructure and resilience discussions, academic literature, and communities such as UKCP18 user groups there are also general recommendations and experience to be drawn from when considering the WCRRA plans.

- In undertaking a vulnerability assessment it is important to consider the relevant scenarios and probability ranges of the climate variables. All the WCRRA plans consider the change in mean annual rainfall to be representative of the changing risk of flooding. However, it may be important to also consider the associated seasonal and extreme values as these may provide a more realistic indication of changing risk patterns. For example, where flash flooding from convective storm events in summer is concerned. This is something that requires discussion with data providers, such as UKCP (see Q9).
- Holistic system vulnerability ("risk") assessment also relies on understanding the changing performance/vulnerability of types of asset with changing weather. Network Rail has conducted extensive "baseline" studies into weather thresholds for operational performance (*e.g*. Network Rail, 2014). However, it is not clear from the WCRRA documents whether these are an integral part of the WCCRA assessment process.
- It is important that metrics for planning, monitoring and evaluation of adaptation be forward looking and meaningful in terms of future climate. ISO 14090 recommends metrics that reflect long-term trajectories and previous studies (TRaCCA) note the importance of the link to real asset performance not simply timetable paths (through delay minutes) which led to a recommendation of a metric for service availability ("journey availability") which could be planned and forecast rather than retrospectively considered. The WCRRA plans currently all reflect historical delay minutes as a metric and cannot therefore predict future disruption for future extreme weather events that have yet to happen (see Q9).
- When ranking climate risks to decide on adaptation priorities it is important that the ranking criteria are clear, and the uncertainty associated with the various estimates involved has been considered. The

prioritisation of risks presented in the WRCCA plans appears to be based on (historical) Schedule 8 values within the context of a changing climate. However, the basis of the low, medium and high categories used is not clear.

Adaptive capacity

A lens for considering the gap of WRCCA practice with others is a baseline established through a review of Network Rail's adaptive capacity against global best practice using the Capacity Diagnosis and Development (CaDD) adaptive capacity assessment metrics (see www.cadd.global for details of the metrics) conducted in 2016 and presented by Network Rail at the third European Climate Change Adaptation (ECCA) conference in Glasgow in 2017. The graphic summary is shown in Figure 5.

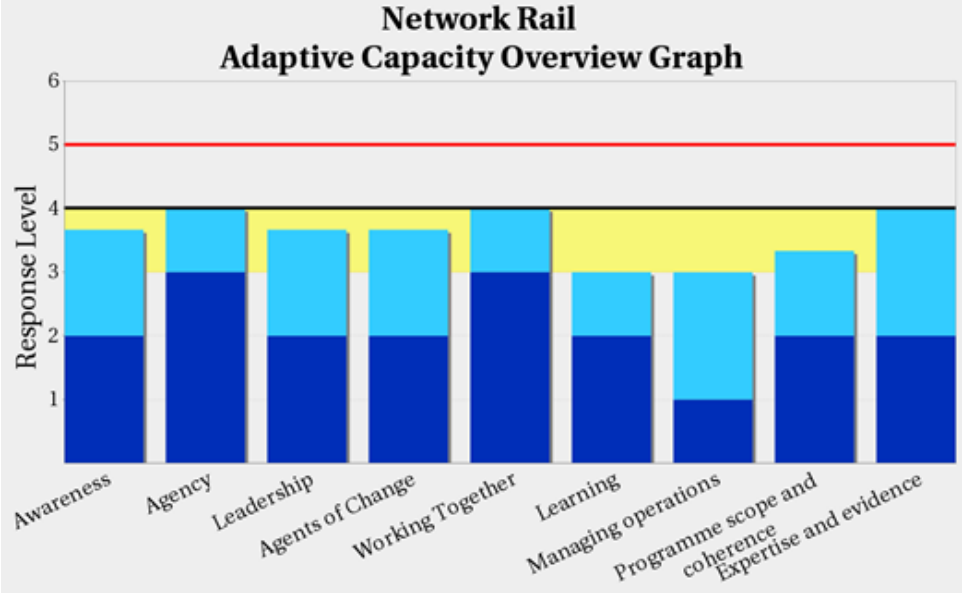

Figure 5: Assessment of Network Rail's adaptive capacity undertaken using CaDD software in 2016 (provided by Trioss)

In Figure 5 the dark blue of each element of adaptive capacity is the level to which there is "solid" practice. Light blue shows the level at which there is work in progress. What is noticeable at the time of this study, whilst "Agency" (being able to identify an adaptation challenge and know what to do about it) was relatively high compared to other capabilities, the transfer of Agency into "Operational Management" was the lowest performing capability. In the WRCCA plans it is clear that the impact assessments will have increased Awareness and Agency amongst other things. Looking at the WRCCA actions it is clear that "Operational Management" remains a lagging capability, since they largely focus on managing current climate (weather) rather than factoring in the future changes that the impact assessment points towards. Developing the capacity to turn understanding of climate impacts into the management of its operations would therefore be the priority focus in the next phase of development for moving Network Rail towards best practice.

The red line denotes the adaptive capacity level that would be required to Network Rail to be fully effective in managing its WRCCA challenges. There remains work to do in all areas.

Whilst Awareness and Agency have been significantly improved through the Impact Assessments, Network Rail recognises that its skills are in asset management, not rail service operation. At network strategy level it sees a risk that proposed options to strengthen the resilience of assets may not be the best way to make the service more resilient. Indeed, these may be more costly than some non-structural service management options. Equally, there is a risk that over focus on non-structural solutions may simply build up the need for structural adaptation in future, leading to an unaffordable investment demand causing significant disruption with a supply chain unable to meet the demand. A balanced asset and service resilience approach could make adaptation investment pathways more affordable and more consistent in terms of cash flow demands and

supply chain requirements. This is an area of awareness and agency that would be useful to develop in future as it moves towards its required adaptive capacity level.

Q15: Does the plan articulate the risks the route is facing and to address this?

Risk from a weather perspective is articulated through historic Schedule 8 costs. Through all the WRCCA plans, the understanding of weather impacts is mentioned in the introduction and impact assessment sections. Each weather impact is ranked according to priority in a table (Table 2, with the exception of Western where it is Table 3) near the beginning of each WRCCA plan impact assessment.

The climate projections commentary in these tables vary in detail between weather impacts. For example, two contrasting statements in terms of level of detail:

- (Regarding wind/lightning) *'Changes difficult to project, however generally expected to increase'*
- (Regarding heat) *'Increases in mean daily maximum daily temperatures range from 2.1°C to 2.6°C (Winter) and 3.2°C to 4.1°C (Summer) by the 2050s. In the 2070s this becomes 2.9°C to 3.9°C and 4.6°C to 5.6°C respectively'* (Values vary by WRCCA; Anglia example shown)

The use of climate change data used is consistent across each WRCCA plan by analysing the same baseline scenario (RCP 6.0 90th percentile). The WRCCA plans also take a route specific approach to these projections by completing their vulnerability analyses according to the appropriate UKCP regions relevant to their routes. However, the vulnerability assessment, like the aforementioned table considers mean daily variations of values (temperature and rainfall). There is little consideration for the most high-impact low-likelihood events such as extreme heat or rainfall, and consequently such risks cannot be accounted for.

All WRCCA plans also mention using UKCP18 RCP8.5 90th percentile projection as *'the sensitivity test on assets with a lifespan beyond 2050'*. In theory this is beneficial as it acknowledges the need to ensure assets can withstand more extreme climatic conditions. However, there is no further discussion of it in any of the WRCCA action plans. Similarly, there is no reference to what assets, or how many may fall into this category so it is not clear how critical this action may or may not need to be.

Nevertheless, actions to address risks across each route are provided in each WRCCA plan impact assessment and summarised in the Action Plans. The CP6 action plan in each table starts with a vulnerability column which can mostly align to a weather impact in the prioritisation tables. Each WRCCA plan varies slightly in how it articulates a vulnerability in their action plans insofar as specifying an asset or location to the weather impact *e.g*. *'falling trees in high winds'* (LNE &EM) or *'Flooding in the Axe Valley'* (Wessex).

Q16: Are the action plans SMART with clearly defined timescales, responsible owners and output measures?

Specific: Each action plan has been approached with different levels of specificity. The most detailed WRCCA plan in this area would be Western which has the largest Action Plan table; all vulnerabilities categorised by primary weather impact, including location-specific actions where necessary. It also goes further than the other WRCCA plans by allocating a Funding Source/Action Lead column. This suggests action ownership, though it is not clear whether Funding Source and Action Lead are mutually exclusive or assumed to be the same accountability. The WRCCA plans have increased levels of specificity where there are more actions points in place.

Measurable: Each CP6 table includes an Expected Benefits and a Resilience Change (with the exception of Western) column. Most of these are generic *e.g*. *"Improved performance"; "Resilience increased"*. As the

actions required typically do not provide a baseline or a quantifiable aspect, they may be difficult to measure. NW&C WRCCA action plan provides the most level of measurable detail; suggesting a % reduction in asset performance/capacities, meeting specific temperature thresholds and referencing return periods for storm events.

Achievable: This cannot be determined without supplementary information such as asset management and repair schedules and plans.

Realistic: This cannot be determined without supplementary information such as asset management and repair schedules and plans.

Timebound: Completion dates are set for almost all actions in all WRCCA plans. Many of these are towards the end of CP6, or specify a year/season. Western's WRCCA plan sets a month and year for most actions. There are some cases in NW & C and Wales's WRCCA plans that also allocate a phased rollout schedule for some tasks which are useful to measure and monitor progress.

Q17: Does the plan sets out resource (financial & competency) requirements, and the approach to address competing priorities and prevent focus on short-term issues?

Financial resource is set out variably across the WRCCA plans. More specifically, the CP6 action plan sets out costs per action. Most actions across the WRCCA plans have a cost allocated to them, with the exception of the Anglia WRCCA plan, where all action costs are set as *"variable"*. On the other hand, Western's plans are explicitly identified to have *'been agreed by the Director of Route Asset Management'* (p.71) and therefore suggests a more comprehensive plan from a financial perspective.

Prioritisation of actions is less clear. With the exception of actions with earlier set completion dates, there is little indication of whether these actions are considered a priority over others. For example, there is no connect of these actions' priorities with those outlined in the impact assessment. Similarly, there is no clear indication of whether each plan is a long/medium/short-term activity, as there is also no start date or duration of activity. There are also "High Priority" but not funded in CP6 tables in each WRCCA plan after the action plan tables. It is unclear whether they are benchmarked as a higher priority than those already addressed in CP6 actions, or whether this assumes all CP6 actions are equally a high priority. Adaptation pathway thinking would help prioritise future actions.

Q18: Are there any actions on establishing measures to monitor resilience and scenario analysis to develop the case for funding?

The Management and Review section of all the WRCCA plans provides an overview of the monitoring processes of the CP6 plans. These sections are very similar across all the WRCCA plans focused on high level management, review and reporting namely:

- Ownership of the Route WRCCA plans by respective Director of Engineering and Asset Management, and monitored by ORR via the holding to account process;
- Regional WRCCA plan implementation updates to the Central WRCCA team twice a year;
- Inputs to a National Asset Management Review Group, and Quality, Health, Safety and Environment Integration Group twice a year;
- Milestone implementation progress reviews by Network Rail Executive Leadership Team and the National Safety, Health and Environment Periodic Report

Monitoring and metrics are also addressed through the Network Rail accountabilities in the National Adaptation Plan objectives (England), Climate Ready Scotland, and the Climate Change Adaptation Plan (CCAP, Wales). However, these linkages are not formalised into processes that continue to monitor resilience.

Q19: Is there clarity on funding paths for the work identified?

As previously mentioned, the extent of funding set out in the CP6 action plans is varied. With the exception of Western's WRCCA plan that provides a Funding Source/Action Lead for each action, accountability is unclear. All the WRCCA plans acknowledge that additional funding sources are requires for additional projects, most of which are outlined in a separate table after the CP6 action plan but there is little to no indication of where additional funding could be sourced.

4. Evaluation

4.1. Maturity of the WRCCA plans

In these WRCCA plans Network Rail demonstrate a relatively high maturity in climate resilient planning in comparison to other rail operators internationally, and other sectors. This is largely achieved through the impact assessment.

The CaDD adaptive capacity maturity framework introduced in Section 3.4 (question 14) has six levels of maturity, which are summarised in Text Box 5 and Figure 6. Evaluating the WRCCA plans using this framework indicates that:

1. At Route level, there are early stages of climate adaptation practice informing policies and strategies;
2. There are some very good examples of adaptation practice reflected in a number of WRCCA plans including Wales, Scotland and Western;
3. Good adaptive practice tends currently to be isolated examples (*e.g*. SWRRP, Section 3.3 Q9). These are not yet mutually supporting or mainstreamed;
4. Some routes *e.g.* Scotland, Wales, Wessex, Western are consciously building capacity development into their WRCCA plans to further mainstream adaptive practice;
5. The detailed information within the impact assessment indicates that there is significant asset management expertise within the organisation;
6. Where there is good adaptive practice, there is often good use of external adaption expertise being brought in *e.g.* using of JBA to provide climate change planning scenarios and Western's work with Arup on the South West Resilience Projects;
7. In general, though there is little line of sight between climate impact assessments and the CP6 activities. Climate risk operations are lagging in maturity compared to awareness of changing risk. Operations are still guided by compliance with processes for managing current climate risk, *i.e*. Schedule 8;
8. The asset management focused expertise of routes may not be sufficiently matched by rail service management expertise to optimise resilience planning for the overall rail services. Optimal resilience planning could bring about pragmatic system-wide management where performance is planned to be regulated in real time according to the nature of the weather hazard and known sites at risk;
9. Some organisational architecture issues within Network Rail may limit the impact of the individual capacities within each route *e.g*.:
    a. The interdependencies between routes, given that 30% of journeys cross route boundaries, are not reflected in the WRCCA plans. More inter-route collaboration in planning could result in more efficient resilience investment *e.g*. heat impacts on rails and electrification systems.

b. A clearer connection between governance of the WRCCA plans and governance of the whole network may enable more systematic review of policies and strategies that affect the adaptation options available to individual routes *e.g*. performance metrics.

Overall, the WRCCA plans are developing a good foundation for doing things differently in the future in terms of "why" and "what". The WRCCA plans provide little detail on "how" to do it differently in the future (e.g. by using the adaptation pathways mentioned at the start of each report) or what to do with the different outcomes.

Box 5: CaDD Response Level – Summary Definitions

Response Level 1: Core Business Focus
Looks at the issue through a short term focus and typically do not recognise that the issue has either got much relevance to them, or believe they are helpless without the support of others (which may of course be true!)

Response Level 2: Stakeholder Responsive
Recognises the need to understand and comply with rules, regulations and financial instruments - keeping up to date with the demands of key stakeholders. There is little action beyond what others say has to be done.

Response Level 3: Efficient Management
Begins to take ownership of operations, to quantify and prioritise issues, put in place common sense and effective management programmes for improvement within the boundaries of business as usual processes.

Response Level 4: Breakthrough Projects
Start to see the limitations of "business as usual" approaches that do not manage strategic threats. They start to explore new ways of working to identify which changes will enable "break through" to more effective approaches

Figure 6: Schematic showing the different levels of organisation resilience

Response Level 5: Strategic Resilience
When the new ways of working are understood, mainstreaming those approaches into a "new normal". To be resilient these new approaches will remain agile within an uncertain future. They will include rapid learning feedback loops to allow delivery experience to update strategic direction.

Response Level 6: Champion Organisations
Some organisations choose to go further and seek to lead wider social change. Understanding these behaviours in organisations is work in progress for Trioss - after 17 years we are *still* gathering sufficient evidence for this level.

Using the CaDD maturity metric the WRCCA plans show Routes to be in a transition phase from Response Level 2; simple compliance, to Response Level 3 efficiently managing climate risk within current business as usual approaches *e.g*. these WRCCA plans. To manage its climate risks with the capacity required, more transformational change will be required *e.g*. the limitations of the WRCCA strategy itself will need to be addressed. It is too early to focus too much on those transformational changes now. Network Rail needs to first make the best use of the information and actions within these WRCCA plans. Once those practices are embedded it will have a strong foundation for exploring what more transformational changes to planning practices will be beneficial.

In conclusion, there are many strengths to the current WRCCA plans, and they should be considered an example of good practice, globally. They are consistent in their approach across the different route regions and provide an evidence-based understanding of current weather vulnerability and impact. They consider a range of weather impacts on a range of assets comprehensively. Network Rail demonstrate a relatively high

maturity in climate resilient planning in comparison to other rail operators internationally, and other sectors. There are areas for improvement (Section 4.2), but Network Rail are showing international leadership with these WRCCA plans.

4.2. Recommendations for CP7 planning and long-term resilience

Building the on the detailed analysis provided in Section 3 and the evaluation of maturity described in Section 4.1, there are several recommendations (numbered **Rx**), falling under two broad areas of improvement, as outlined below.

1. Future WRCCA plans must be broader in scope, considering cross-cutting risks and interdependencies, and the extremes of weather and longer-term climate change, including so-called "worst-case" scenarios.

The current approach using Schedule 8 and operational performance considers the impact of current hazards to plan for the future. However, under a changing climate, there will be risks from yet unexperienced events, such as flooding associated with future sea-level rise, or heat or rainfall extremes beyond current known experiences. Indeed, climate observations show an increase in the frequency and intensity of extreme events such as rainfall and heat (Met Office, 2019). The Vulnerability Assessment in the WRCCA plans does not currently consider changes in extreme rainfall and the projections used for river flow uplifts are dated (based on UKCP09). Not all action plans include all vulnerabilities or impacts (*e.g.* reducing risk to staff from extreme weather).

- **R1:** The WRCCA plan Vulnerability Assessment should consider current and future extreme precipitation.
- **R2:** The river flow uplifts used in the Vulnerability Assessment should be updated to incorporate new climate projections (UKCP18), paying particular attention to how precipitation extremes are incorporated within these uplifts, as per R1.
- **R3:** All routes should consider all vulnerabilities and impacts but apply different emphasis to suit the local primary factors of concern.

The Vulnerability and Impact Assessments considered each hazard in isolation, whereas extreme weather typically combines several hazards. For example, in summer 2015, a short duration heat wave, intense rainfall, and lightning caused significant impacts on railway operations across the network (Ferranti *et al.,* 2018). Whilst climate modelling data does not always provide integrated evidence, the application of expert judgement those involved with WRCCA plans should identify many of these risks. On some areas external support may be useful *e.g*. the implications of changing levels of ground water, driven by both rainfall and sea-level rise on changing flood risk from peak river flows.

- **R4:** The Vulnerability Assessment should consider multi-hazards, and how these may change in the future (albeit noting the limitation of current climate modelling ability in this area).
- **R5:** The Impact Assessment should report on multi-hazards and their collective impact.

WRCCA planning needs to take greater consideration of changing extreme climate events over the life of investments. The introduction section of all WRCCA plans notes the importance of using the higher-end climate change scenario, RCP8.5 90th percentile, to stress test longer-life assets. It is not clear how or if this was undertaken. Adaptation plans for other long-life infrastructure such as the Thames Barrier also consider the sensitivity to high-end low-likelihood climate change, for example using the Met Office H++ scenarios (Ranger *et al*., 2013). This is considered good practice *e.g.* UKCP18 sea-level rise guidance and Defra flood planning guidance (EA, 2020). WRCCA plans should report on the sensitivity analysis to high case and ideally H++ scenarios.

- **R6**: Longer-life assets should be stress tested in line with best practice guidance acknowledged the WRCCA plans.

- **R7**: The sensitivity of longer-life assets to increasing slow onset changes and frequency and intensity of extreme events evaluated to the level of high-end low likelihood probability should be considered in future WRCCA plans.

Sea-level rise is considered using RCP 4.5 95th percentile data; this is a conservative estimate of sea-level change, and current best practice advocates considering H++ scenarios as a sensitivity test for nationally significant infrastructure (EA, 2020). Future WRCCA plans should reflect more current UKCP18 high case sea-level rise scenarios and sensitivity analysis to H++ scenarios indicated in UKCP18 (see Fung *et al.*, 2018 for more information on sea level rise and storm surges in the UK).

- **R8**: Network Rail should use less conservative estimates of sea level rise in the Vulnerability Assessments of the WRCCA plans, particularly for longer-life assets (see R7).

Although climate change is acknowledged as a long-term risk via the consideration of future climate scenarios up to the 2070s, the long-term approach to managing this risk is unclear, and actions focus on the CP6 delivery period. Moreover, it was unclear when actions for which there was no funding available for CP6 will be undertaken, or how actions had been prioritised for funding within the plans. Adaptation pathways that encompass multiple CPs can help prioritise immediate actions and funding, and allocate actions and budget to actions that can be delivered in a subsequent CP. This enables longer-term risk management and provides continuity for climate adaptation across the CPs (*e.g.* Thames Water, 2019a). This approach will give network and wider transport planners as well as regulators an understanding of the long-term strategic risks and opportunities that need to be managed. Forthcoming guidance includes: BS 8631: Adaptation to climate change - Using adaptation pathways for decision making.

- **R9**: Network Rail should use adaptation pathways (as acknowledged in the WRCCA plans) as a tool to link actions across different CPs and enable long-term planning for climate change, particularly for longer-life assets.
- **R10**: The WRCCA plans should explain how actions are prioritised for specific CP funding.
- **R11:** Network Rail should consider aligning WRCCA plans with ISO or BS standards for adapting to climate change.

The Vulnerability Assessment section of all WRCCA plans notes the interdependencies between rail and other sectors such as economy, power, telecoms and water infrastructure. It is not evident how interdependencies with other sectors are systematically evaluated. Moreover, interdependencies with other strategies such as the transition to Net-Zero need to be evaluated. An example of a cross-cutting risk in the transport sector is potentially an electrification programme in order to reduce greenhouse-gas emissions. Track-lowering can be utilised to gain clearances under over-bridges. However this technique may result in waterlogging and flood hazards, which will be exacerbated through climate change.

- **R12:** WRCCA plans should have a consistent reporting requirement to identify key interdependencies and how they are being managed.
- **R13:** Network Rail should consider the risks associated with transitioning to a low-carbon economy and its potential implications for weather and climate resilience (*e.g.* See Anglian Water, 2020).

There are some terms used that may be defined in other documents, such as the WRCCA strategy. Ideally they should be defined in these plans to aid understanding and consistency between WRCCA plans and the WRCCA strategy.

- **R14:** Key terms such as adaptation and resilience should be defined in a glossary.

2. A new enabling environment is required to support the continuing maturity of the WRCCA plans and broader WRCCA strategy. This includes reviewing: (i) the metrics used for weather and climate resilience;

(ii) the current processes for monitoring resilience improvements; and (iii) the governance of WRCCA across the organisation.

The Impact Assessment is based on performance impact and Schedule 8 data. This backward-looking metric provides a good basis for analysing current weather impact, but it does not permit preparations for future change in the degree or frequency of hazards. Moreover, Schedule 8 measures adherence to timetables – this does not necessarily reflect infrastructure resilience to weather and climate nor does it give future value to the network. Effective metrics are needed to strengthen the link between UKCP analysis and action plans, acknowledge the system resilience value of actions that are weakly linked to current service metrics (*i.e.* CaSL, PPM and Schedule 8) and reward decisions, which reduce costs over the whole life of a decision/investment.

- **R15:** Network Rail should review the metrics used to measure weather impact (see Box 4).

Best practice adaptation planning, as outlined in ISO 14090, requires implementation plans, indicators and arrangements for monitoring and evaluating progress in achieving adaptation. There was no evidence of such indicators, or detailed processes to monitor and evaluate the effectiveness of the WRCCA activities related to resilience and adaptation. These need to be implemented moving forwards so that Network Rail can understand how their infrastructure resilience is changing. Indicators should be developed that are system-wide, focussed on the resilience contribution to performance of all assets on a route or portion of a route. These indicators should be derived from knowledge of asset behaviour in different types of climate/ weather. The indicator could then be used for benchmarking, and could be monitored and evaluated both in "real time" during future time periods and for projected future weather/ climate scenarios. Such an indicator would meet ISO 14090 needs, to show actual or projected improvement or deterioration of assets within routes by giving ways to understand the trajectory of adaptation activity identified within the WRCCA plan. Additionally, it could usefully be used to help target resilience related to different weather categories as used in Network Rail standards (*i.e.* normal/ adverse/ extreme) under a service level agreement. This last point could bring about pragmatic system-wide management where performance is planned to be regulated in real time according to the nature of the weather hazard and known sites at risk.

- **R16:** Network Rail should implement indicators to monitor and evaluate changes to infrastructure resilience (see also R11).

The WRCCA plans did not demonstrate a clear line of sight to asset management; although owned by the DRAM, the WRCCA actions did not explicitly link with actions within other management plans (*e.g*. vegetation management, drainage management).

- **R17:** Actions in the WRCCA plan should link to directly to actions in the relevant asset management plans.
- **R18**: The WRCCA plans should be embedded within the new governance structure, which should clearly articulate ownership and accountability for the WRCCA plan actions.

Transformational change such as (re-routing or closure of lines) may be required to detail with some weather hazards, or longer-term change (*e.g.* sea-level rise), *i.e*. reaching a "tipping point". There are currently no means to consider this within the WRCCA process. This should be reported as part of the analyses produced through the intended adaptation pathways planning approach.

- **R19:** Future WRCCA plans should contain transformational change and tipping points (see also R9).

Some hazards occur across multiple regions, or a weather hazard occurring at a critical location such as near Birmingham New Street (Jaroszweski, *et al.,* 2015) or Manchester Piccadilly (*e.g*. Ferranti *et al*., 2018) can propagate across the entire network. The Route level approach to resilience is articulated within the WRCCA plans, but governance of the hazard (*e.g.* flooding) or 'whole route' resilience thinking was not clear.

- **R20:** Future WRCCA plans should consider the governance of hazards that have network wide impacts.

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Appendix One

Coding methodology: WRCCA plan contents analysis

The coding of the WRCCA plans was formulated to directly address the questions outlined in section 3. Each WRCCA plan was downloaded as a PDF and reviewed through a textual analysis with supplementary keyword search where relevant according to the question. Where in-text evidence was found that directly addressed a question, this was highlighted in the PDF document, with an annotation to which question it referred to. As the questions were grouped into four themes, the coding was designed as follows:

- Terminology & Scope
- Strategic Alignment & Integration
- Adaptation Planning
- Actions Plans & Best Practice

There are some instances where a section of text addresses more than one question. Such text is highlighted *per* question and thus may have separate annotations for each question.

The highlighted evidence was summarised and captured in a spreadsheet, with a tab referring to each theme. Each row referred to a question, while each column referred to a WRCCA plan file (*i.e.* one column for each route). The spreadsheet therefore produced a summary of evidence for each question across the WRCCA plans at a glance, in order to identify similarities and differences in each route's content to address the questions.