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RAIL ADAPT

Adapting the railway for the future

UNIVERSITY OF BIRMINGHAM

INTERNATIONAL UNION OF RAILWAYS

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Summary for Executives

Climate Change:

- is a long term, slow acting, but very high impact risk;
- affects all parts of railways in all parts of the world but in many different ways;
- can have beneficial effects but effects can also be catastrophic;
- requires leadership to plan and change but there is the knowledge and the tools to achieve this.

- Where does Climate Change feature in your risk register?
- How well prepared is your organisation to manage the risks?
- Are you asking the right questions about your assets' future and your investment criteria?
- Do you have Climate Change adaptation embedded in all departments?
- Are you communicating with stakeholders so that everyone has a shared understanding?

These are some of the questions that directors should be asking and answering to ensure the long-term health and sustainability of the organisations they lead, and of the railway sector generally.

This framework document sets out the context of climate change, the issues at stake, strategies and toolkits for dealing with them. It helps railways to support government commitments such as the Paris agreement on climate change, the UN Sustainable Development Goals and National Adaptation Plans. It offers case studies to show how railways in different parts of the world are dealing with them today. It provides techniques and tools, adapted from other areas of risk management and from the varied experiences of engineers, operators and planners in different regions of the world, facing different challenges. Challenges that you will face tomorrow are being managed somewhere in the world today, by asset managers, railway operators, rolling stock engineers, scenario planners and many others, and this framework and guidance document is designed to support both directors and departmental managers in anticipating and facing up to those challenges

An adaptive railway organisation is one that adjusts intelligently to the changing climate, delivering service sustainably with value for money.

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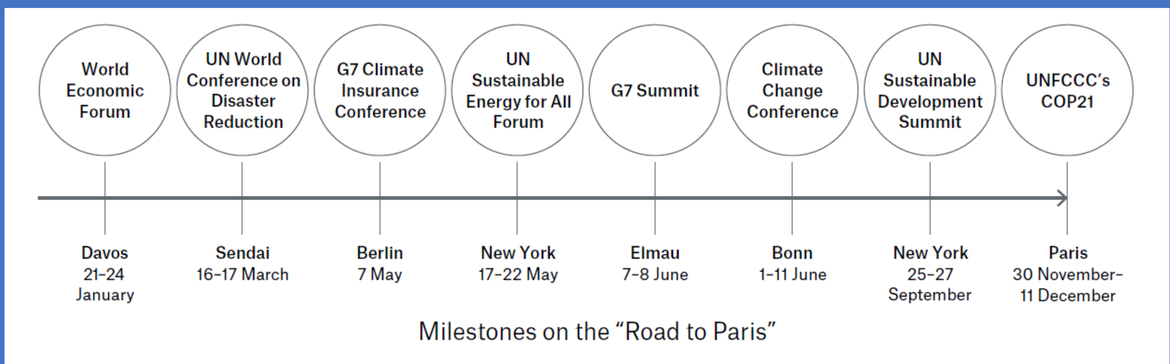
1. Introduction

The climate is changing. Globally, weather records are broken almost every year. Locally, the effects of floods, drought and other extreme weather events are disrupting railway operations more frequently, with an associated loss of revenue and potential long-term loss of business. In addition, the market is changing in other ways, with shifting populations, migration and economic development. Whilst initially a threat, this presents railways with opportunities for economic development through expanding markets and linking with other service providers to generate new business, for example through sustainable multi-modal transport (UIC, 2015).

Recent international agreements, such as the Paris agreement on climate change, the Sendai agreement on disaster risk reduction, and the international adoption of the UN Sustainable Development Goals, have strong alignment and commonality. They describe the need for actions that combine greenhouse gas emission reduction with sustainable development and climate change adaptation, in order to reduce and mitigate risk to individuals, businesses and communities. National governments and authorities are developing and implementing National Adaptation Plans, which often call on industrial sectors to develop and report progress on a regular basis.



In 2015, a series of conferences on sustainable development, disaster risk reduction and climate change, led to the Paris agreement at COP21 (After MunichRe 2016).

Adaptation also makes good commercial sense. Disruption of transport operations and infrastructure by extreme weather damages both revenue and reputation for rail operations. Rail has a unique opportunity to build on its excellent reputation as a reliable and environmentally sound transport mode, encouraging the shift from road to rail for both passengers and freight, and utilising new technology. Railways can thus attract national and international investment, as well as increase their role in reducing greenhouse gas emissions. Ultimately, this will drive economic development and improve national and local resilience to climate change.

Legally directors of organisations also typically have a ‘duty of care and diligence’ and climate change is now seen as a risk that is both capable of causing harm and can be foreseen. Therefore, directors should be considering the impact on their business and failure to do so may bring liability for future losses (Hutley & Hartford-Davis, 2016).

The Rail Adapt vision is for “**a transport system in which the world's railways have acquired the flexibility to intelligently adjust to climate change, thereby providing their economies and societies with reliable and cost-efficient transportation services**”.

To be considered as climate adapted, the railway must:

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

2: comprehend the range of current and future weather conditions which will affect it and have operational and management strategies in place which enable it to respond both in the present and over time to weather challenges;

3: comprehend how climate change may affect its range of operating conditions over time and be evolving its operating and management strategies at least at the same rate as the climate affecting it;

4: adapt to climate change as part of business as usual such that the cost of adaptation has only marginal impact on its financial performance.

The well adapted railway therefore has enhanced anticipatory capacity, adaptive capacity and absorptive capacity to deal with the changing world.

This report proposes a framework, developed in partnership with rail sector stakeholders, that enables railway organisations to generate and implement their own distinct and effective adaptation plans. The approach enables and explains, rather than prescribes. It informs, highlights and collates examples, bringing together best practice which can be tailored to local needs and strengths, whatever the resource limitations or scale. It fits within the UIC global vision for railway development (UIC, 2015).

Importantly, **the Rail Adapt vision and framework foresee not a ‘special project’ or new undertaking for rail organisations but adaptation integrated with business as usual**, bringing together elements which may currently be disparate or separated in order to improve business outcomes. The framework is thus not advocating a new

Resilience

Resilience is defined here as the ability of a rail organisation to provide services effectively and sustainably as the climate changes. This includes elements of Robustness, the ability to resist disruption; Redundancy, the ability to use backup facilities to provide service during disruption; and Recovery, the ability to rapidly return to service after disruption.

Adaptation

Adaptation is the process of making changes to how services are delivered to be resilient to disruption now and in the future. These might be physical changes to infrastructure but also include organisational changes to enable intelligent adjustments to how services are provided, foresight of problems and learning from experience.

department but facilitates action across all existing ones. Thereby, new understanding can be built into existing processes and projects, consequently enabling better results.

The framework has been developed through consultation with the railway industry globally. Workshops were held at the global railway sustainability conference in Vienna in October 2016, London in April 2017, Beijing in June 2017, and at the September 2017 Climate Change Conference in Agadir, which have helped to shape the framework with the experiences and current best practice of over 50 organisations from 20 countries. It also reflects current developments in other modes, such as the PIANC World Association for Waterborne Transport Infrastructure guidance (2017) to ports and PIARC World Road Association adaptation framework (2015). It links directly to the recommendations of organisations such as the World Bank, OECD and International Transport Forum. This has been supplemented by individual discussions with representatives of railway organisations and consultation on the draft report.

1.1. Gauging current progress

Organisations across the world are at many different stages in understanding and preparedness for climate change. Some are already nationally and internationally active whilst others have less experience and support. The framework presented here does not assume any current level of proficiency or knowledge of adaptation or climate change and can be used to improve current plans or start afresh.

The changing climate has many varied impacts on railways. Some, such as sea level rise, will develop slowly. However, a far more obvious impact is an increase in the frequency and disruption caused by extreme weather events (Bradbury & Deconcini, 2012; Hsiang et al, 2017). How an organisation responds during extreme weather can therefore provide a useful indication of how well adapted that organisation is at present.

Ask yourself - **How does your organisation typically react when there is extreme weather?**

No doubt everyone in your organisation reacts to continue delivering services and cope with the situation but is this a planned and coordinated reaction? Has the situation been foreseen and prepared for or is it something the experienced members of staff 'just know' how to cope with and what to do? Have new staff been trained in how to react and what they may need to do? Has this planning and preparation been done locally or across the entire organisation? Does it link with other organisations in the supply chain such as maintenance contractors, electricity providers or other transport agencies that you deal with on regular basis, and on whom you depend or who depend on you? Have you developed forecasting systems which can translate weather information into warning of different types of disruption risk? How far in advance is your horizon for planning and preparation for the potential disruption by extreme weather? Is this preparation part of your normal business planning or something separate?

The answers to such questions can help to place your organisation on the preparedness scale. Such preparedness arises from the organisational capacity and is something that can be developed through organisational structure, communication and training – as outlined in section 4. However, as the US Department of Transportation notes "no agency is an island" and rail service providers rely on energy, water, waste, road and many other services to function. Equally rail services are relied on as a lifeline and as an enabler of businesses throughout the economy.

An example preparedness scale

Describing the organisational response to disruption can help to identify preparedness for future events.

Level 4 : The organisation has a long-term plan for development which includes sustainable resilience to climate change as part of their business. This includes how it copes with extreme weather in terms of asset management, staff training, forecasting problems before they occur, and stakeholder co-operation. After the disruption, the organisation seeks to learn from the experience and improve.

Level 3 : The organisation has short-term plans to deal with extreme weather, both at a local-level and nationally, which are linked to some forecasting of problems. The response often relies on experienced staff with tacit knowledge who can put these plans into action. Afterwards the priority of the organisation is to return to normal service as quickly as possible.

Level 2 : The organisation has an understanding of the kinds of problems that can occur but relies on experienced staff to react appropriately when they occur. After the disruption, the priority of the organisation is to return to providing normal services.

Level 1 : The organisation reacts to each disruption as it occurs, relying on experienced staff to cope as best they can.

MTR example of preparedness

The major public transport network serving Hong Kong is provided by MTR through a multi-modal network of light and heavy rail with associated bus services. MTR have been working with the Hong Kong Observatory since 2015 to identify risks from extreme weather events across the MTR railway network, including stations at risk of flooding or landslides due to heavy rainfall. MTR also regularly review their Design Standard Manual to ensure that new railway projects are built with appropriate protection for rainfall events throughout their design lifetime.

To ensure safe and reliable service for customers the existing railway infrastructure is also inspected and assessed on a regular basis to ensure its robustness in extreme weather events. MTR recently retrofitted station flood boards with increased height to protect the critical equipment because of this increased rainfall risk and regularly inspect slopes to assess landslide risk before the rainy season.

Frontline staff have special training to support passengers during heavy rain and typhoons and special flood response teams are prepared to deal with problems. MTR are also implementing heat stress prevention measures and guidelines for staff and contractors across their network during hot summer months, including increasing the maintenance schedules for critical HVAC equipment.

MTR has published information for passengers through its Typhoon Travelling Tips (MTR 2017), a guide to promote safe travel for passengers during extreme weather. These not only guide passengers to information before and during events but also increase awareness of the steps MTR are taking to ensure a safe and reliable service.

Adaptation is directly related to improving the preparedness of organisations, increasing their capacity to deal with unexpected events. Examples of this include improving forecasting to give more accurate or greater periods of warning, improving communication and training so that the tacit knowledge of experienced staff is distributed more widely. A key part of this is identifying where your organisation has expertise that can be used more widely or effectively, both internally and externally, and where it needs to engage with external organisations to develop or bring in such expertise through partnership.

An excellent example of this is the partnership of railway organisations with meteorological forecast providers and climatologists. The climate is complex, and the scientific understanding of climatic processes and climate change is rapidly improving and advancing. Few railway organisations can effectively develop this in-house expertise but partnerships with national and international meteorological organisations can provide the needed expert knowledge. However, meteorologists are not railway experts and for the partnership to be effective this meteorological and climatic knowledge must be interpreted into a form that is relevant to railway organisations. Therefore, it is vital that this engagement is a partnership, the significance of which should not be underestimated.

Another important partnership is that between rail organisations and local authorities, road agencies, and other transport groups. Many disruptive events effect everyone in a region and working together can provide additional benefits such as priority clearance of snow from railway access points, alternative transport provision, and the joint development of new opportunities for projects or services. Looking at local problems from a multi-modal perspective brings opportunities for joint or shared

Multi-modal response

The Metropolitan Transportation Commission and California Adaptation Forum participated in the Adapting to Rising Tides work to increase preparedness and resilience of San Francisco to sea level rise and other climate change impacts, including protecting both road and rail transportation.

The actions undertaken because of this hazard and vulnerability assessment included:

- engineering solutions such as enhancing natural shoreline protection and drainage system modifications;
- operational planning such as emergency management plans and actions that could be integrated into normal maintenance;
- organisational enhancements including information sharing and coordination of actions and planning for mutual support;
- knowledge development undertaking specific studies where there was insufficient information for assessment.

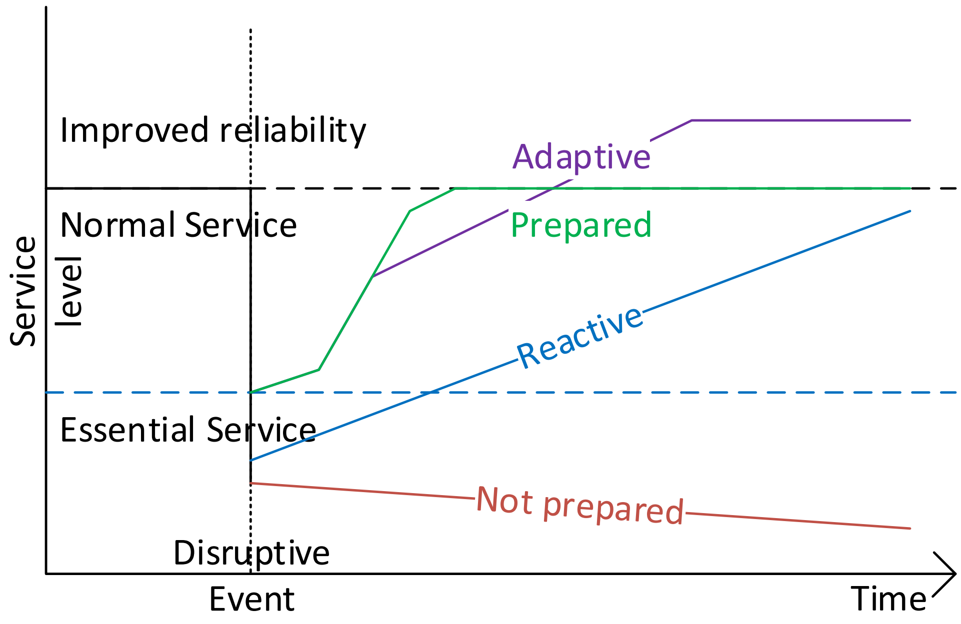
approaches to working during disruptions, purchase of equipment or metrological services and passenger, freight user and stakeholder engagement.

Your organisation also has existing expertise that can be utilised in adaptation. For example, you may be using or working toward ISO55000 in asset management, ISO14000/9000 for quality assurance, ISO26000 covering social responsibility and environmental impacts, ISO31000 in risk management for safety and financial planning or even ISO22316 for organisational resilience. Building on internal expertise to address resilience and adaptation is effective because it already contains a good understanding of your business and is integrated within the organisation. This integration is important because new initiatives and departments can meet with resistance from other parts of the organisation as they represent change. Working toward the common goal of improving services is more likely to be successful.

Enable these internal experts to address adaptation by linking them through partnerships with experts in subjects such as:

- Transport Planning and engineering
- Environmental science and engineering
- Meteorology and climatology
- Hydraulic and hydrological engineering
- Geology and geotechnical engineering

Engagement within, and with stakeholders outside, will enable the organisation to enhance preparedness and, by learning from events, improve reliability and service over time.



Case Study: Austria - UBIMET and ÖBB

Railway and Meteorology Partnership

infra:wetter

Austrian Federal Railways (ÖBB) manage rail infrastructure and operate passenger and freight train services in Austria. Since 2005, there has been a partnership between ÖBB and the weather service provider UBIMET. The key element of this partnership has been the jointly developed bespoke weather information system **infra:wetter** providing 24/7 severe weather alerts and forecasts for the Austrian rail network.

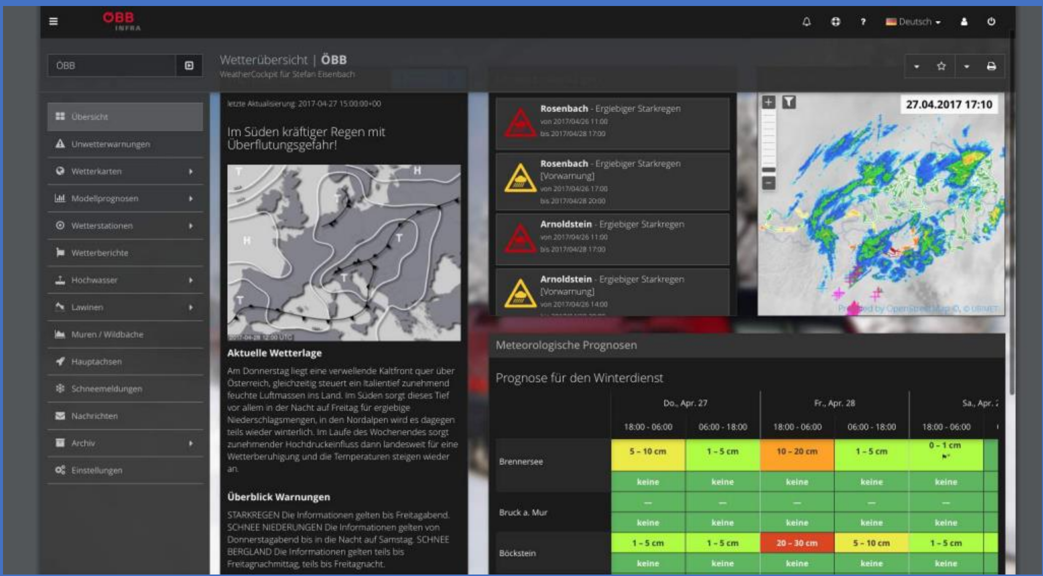
The objectives of **infra:wetter** are to design, develop, provide and operate a flexible and extendable nationwide weather information system, including a meteorological monitoring and warning network of weather stations and alarm systems, to observe local conditions and detect when hazards occur that present a risk to the railway.

infra:wetter requires a combination of both meteorological and railway expertise in order to develop high-resolution modelling capability that can translate weather information into practical guidance for railway decision making. On-demand forecasts of key weather parameters tailored to specific routes, stations or critical locations can inform the planning of railway operations days ahead of an event, increasing preparedness and response capacity.

Severe weather warnings, that are standardised and replicable, can be issued when hazardous conditions are expected in high-risk or critical parts of the railway. Each "Weather Warning Section" has a specific set of actions that should be carried out when a warning is received, to ensure the safety of rail operations. Alarms located at key locations, such as bridges with a known flood risk, can provide an early warning of potential hazards allowing routes to be closed or speed restrictions imposed before the track is affected. Fire risk is also a specific area of focus.

infra:wetter also aims to provide mid-range extreme weather outlooks, for example, the amount of winter snowfall. This information can allow programmes for clearing snow to be scheduled effectively and resources optimised. Mid-range extreme weather outlooks can also be used in the planning of winter services and timetables.

All information from **infra:wetter** is accessible via a central interactive online portal. This provides a communications centre for weather warnings, reports from employees and live weather station readings. The portal is adapted for smartphones, meaning that employees in any location across the network can have access to live weather information and respond accordingly.



For future projects, such as new railway lines, information from **infra:wetter** can be used to identify local hazards and assess the potential impact of extreme weather on daily operations. High resolution simulation and analysis of local weather conditions is required before including climate change projections, to identify clear impacts on operations.

Weather models can also be improved to provide capability for the automation of processes on the railway network. Research is required to create the rules for such processes and to optimise the interaction of weather and railway management. Improved models will require high update cycles and data interfacing with internal steering software. A more automated approach to managing extreme weather hazards on the railway, including complete natural hazards mapping, is under development.

It is critical to have strong and effective leadership and a shared vision to implement any organisational changes needed to improve resilience to weather and climate. For example, the company strategy or vision statement should recognise adaptation; company performance should include indicators of preparedness and clear responsibility for these should be owned by the executive management. Existing expertise may reside within different units or departments of your organisation, or with external organisations such as suppliers or contractors, and these units will need to be brought together in new partnerships. Accordingly, this framework has been designed to assist in the process by outlining what the shared vision of weather and climate resilience may look like, what steps may be required in achieving adaptation, and where external inputs may be most valuable.

The framework is divided into two sections reflecting the two halves of the process; (i) developing an adaptation strategy; and (ii) implementing adaption.

The following key principles are embodied in both halves of the framework:

- No matter the cause, the climate is changing
- World economics, population and social patterns are also changing, and in turn driving changes in transport demand
- Railway organisations have expertise and experience to deal with these changes
- Non-railway organisations have potentially valuable complementary expertise and experience to share
- Railway organisations are part of larger national and international networks (of multi-modal transport, economy and governance) which enable and regulate what can be done

The framework itself provides a structure through which an individual or organisation can review and assess for themselves what actions they are taking, what further actions may be necessary and who might best be placed to undertake these actions. The end goal, embodied in the vision statement, is an organisation that can change and adapt intelligently depending on the circumstances. This imagines that adaptation actions become a part of business as usual rather than a special project or process, because the world will continue to change. Adaptation is likely to be needed at all levels of the railway business and it will take many different forms. **Adaptation therefore must involve people from across the organisation each considering it from their perspective.** It is critical that these people are empowered to work together and enable, rather than impede, each other. Reaching this point and managing the organisational change may require short-term actions to bring people together, but the ultimate goal is to change the organisational approach in the long-term in order to embed resilience to extreme weather and climate change at all levels of the organisation.

Case Study: Finland - Finnish Transport Agency (FTA)

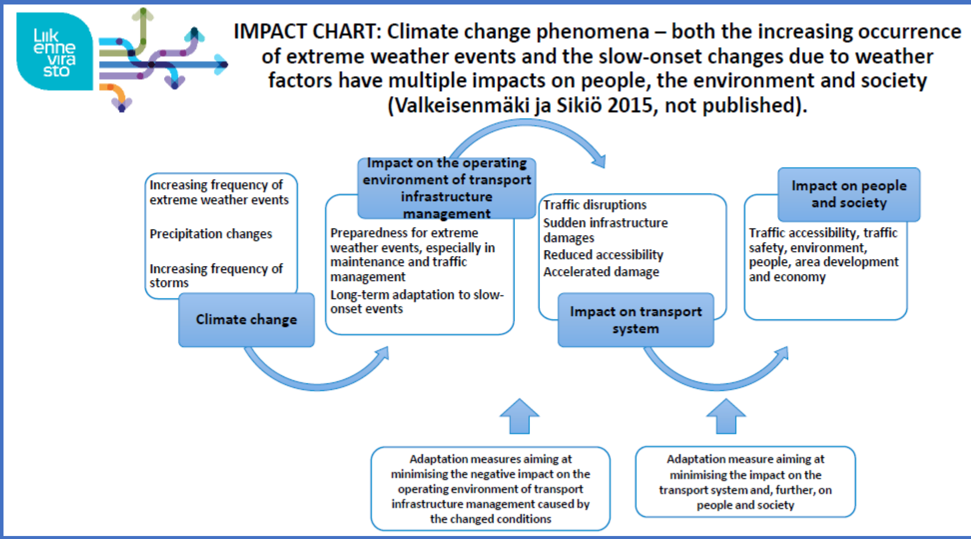
State-of-the-art adaptation in Finland

The Finnish Transport Agency (FTA) is a multidisciplinary expert organisation, contributing to the development of Finland's transport system through promoting traffic safety, sustainable development, and efficient travel. FTA are responsible for the management and maintenance of the Finnish rail network to maintain full operating conditions, spending nearly 200 million Euro per year on track maintenance.

Infrastructure can provide a platform for growth, and with FTA having a 20% share of Finland's total infrastructure market they are in a strong position to lead the development of the country's rail network. However, Finland is projected to face a variety of natural hazards due to climate change which require astute management to maintain economic growth. The temperature increase in Finland is expected to be more than 1.5 times the global mean warming, along with a substantial projected increase in precipitation. This may have significant consequences for railway infrastructure, as well as changes in freeze-thaw cycles, snowfall, strong winds and lightning.

In Finland only preliminary estimates have been made on the economic impacts of climate change. These have included sectoral estimates of changes in net value added for sectors such as energy, agriculture and insurance. However, extreme weather events can have significant local costs, such as flooding in Pori in 2007 causing an estimated 20 million Euro of damage. So far little research has been carried out on the health and societal impacts of climate change in Finland. However, adaptation to climate change requires a more holistic approach than focusing on pure economic consequences. Transboundary effects of global climate change must be understood, and their repercussions for Finland. The resilience of the built environment to climate change must be reinforced, whilst also building the adaptive capacity of society, which may require significant investment to achieve.

The ‘Impact Chart’ below demonstrates an approach to assessing the chain of impacts of climate change on infrastructure management, transport operations and society, with the need for adaptation interventions at multiple levels.



An effective policy and legal framework is required in order to implement such interventions. Finland’s National Strategy for Adaptation to Climate Change (2005) is supported by a series of key programmes and strategies. A parliamentary working group now exists to define the actions necessary for developing the Finnish transport network, meeting emission reduction targets, and promoting automatisation and digital growth. The Climate Policy Programme for the Ministry of Transport and Communications’ administrative sector 2009-2020 outlines a series of measures for adaptation for which progress must be reported annually, recently including protection and rescue planning along with tree removal to prevent storm damage.

Key priorities for transport infrastructure management in Finland involve integrating adaptation into all activities, collecting data for vital risk assessment methods and harnessing the positive impacts of climate change. Rail specific adaptation includes strengthening and protecting structures, developing warning and monitoring systems with weather providers and improving rescue services and safety information.

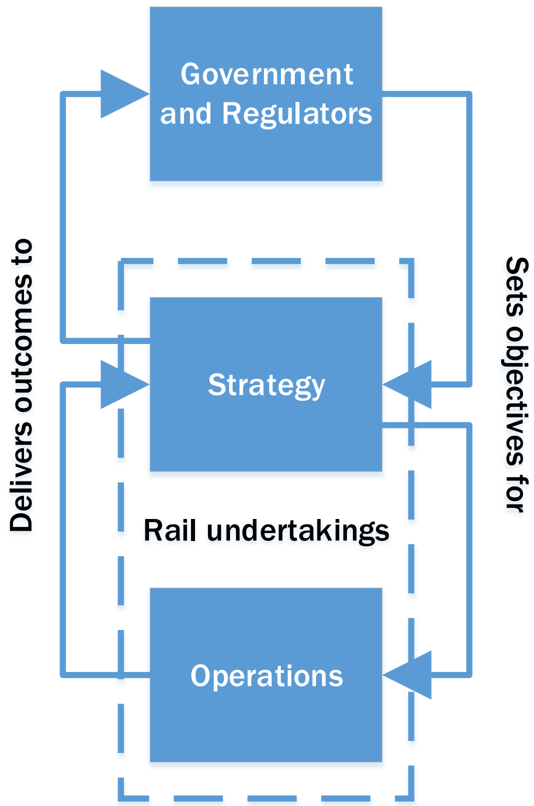
The key message is the importance of first understanding the risks posed by climate change in order to make informed decisions on specific adaptation and preparedness measures to implement.

2. The Rail Adapt framework

2.1. Objectives and policy interactions

The Rail Adapt framework is flexible and applicable to railway organisations of all sizes and types, including divisions or parts of larger organisations. It is designed to enable each organisation to make progress in adaptation and improve their preparedness to climate change. It embodies an iterative process and therefore the framework is circular, with feedback from each iteration to the next. However, it also recognises that no organisation exists or operates alone and therefore within each iteration there will be various engagements with other stakeholders and organisations.

The first flowchart helps set the initial objectives for the development of an Adaptation Strategy (as outlined in the next section). Such objectives may be defined entirely from within an organisation but may also be partially defined by other organisations. After all, a railway organisation is often part of a broader railway sector, which may have national regulation, and within which there will be groups that define the organisation's strategy whilst others deliver operational services. Adaptation can and should be part of all of these groups and this framework is intended to be applicable to all these levels. However, the objectives at one level may be directed or constrained, in whole or in part, by the levels above and in turn the delivery of adaptation may contribute to the achievement of the objectives of the higher level.



For example, railway organisations may be, or may wish to be, directly integrated into their National Adaptation Plans, or to contribute towards their governments' commitment to deliver the emission targets of the Paris agreement on climate change and Sustainable Development Goals 9 and 13. Such initiatives are also useful in demonstrating engagement with regulators, securing finance for new development or participating in international and multi-modal transport projects.

Western Australia – Managing Fire and Flood

In WA, a state larger than many countries, critical road and rail links are at risk from a variety of hazards including extreme heat, flooding and bush fires. A series of legal provisions now mandates coordinated strategies and planning across sectors and networks to address resilience. This has led to the development of an organisational culture that can provide minimum service levels during disruption due to emergencies and quickly return to full operations through effective planning for recovery. New technology such as satellite imagery of bush fires is helping to provide new management options and information for decision support.

The Organisation for Economic Cooperation and Development (OECD) assists countries with policy development to assess and prepare for climate change. OECD identifies the inherent links between climate risks, and the measures to address them, and other policies such as economic development. Integrating adaptation planning with other such relevant decisions, for instance regarding land use planning and resource management, improves the efficiency and effectiveness of adaptation. This incorporation into normal decision making ensures that adaptation priorities are aligned with other policy priorities and not a special case or worse, driving perverse outcomes such as deterring investment in resilience or encouraging development in vulnerable areas (OECD 2015a).

OECD is also tracking the progress of NAPs and advocates robust monitoring and evaluation of progress in adaptation to inform policy development and implementation in their regions. The Rail Adapt framework is consistent with the OECD recommended policy development process (OECD 2015b) and therefore can be used directly by railway organisations to support policy development and implementation. OECD maintain a portal for Climate Change at OECD (2016) which includes documents and discussion of policy approaches, financial support and evaluation.

Such adaptation policies fit within the wider scope of local, regional and international transport policies. For example, the EU has recently worked with the African Union to provide transport policy harmonisation and transport sector services development (Shelley & Chatelin, 2016). Such regional and international policy frameworks commonly stress the need for sustainable multi-modal development and the linkage between the mitigation of GHG emissions and adaptation priorities.

If such objectives are part of the organisation's adaptation process measuring and reporting the progress in achieving them need to be included in the planning and implementation process. It can also be important to be aware of any conflict between the external objectives and internal development of preparedness through adaptation so that the strategy and implementation process are focussed on long-term development for your organisation.

Linking climate-related risks to corporate objectives

The Highways Agency has been explicit in its Adaptation Strategy about the link to corporate objectives and risks:

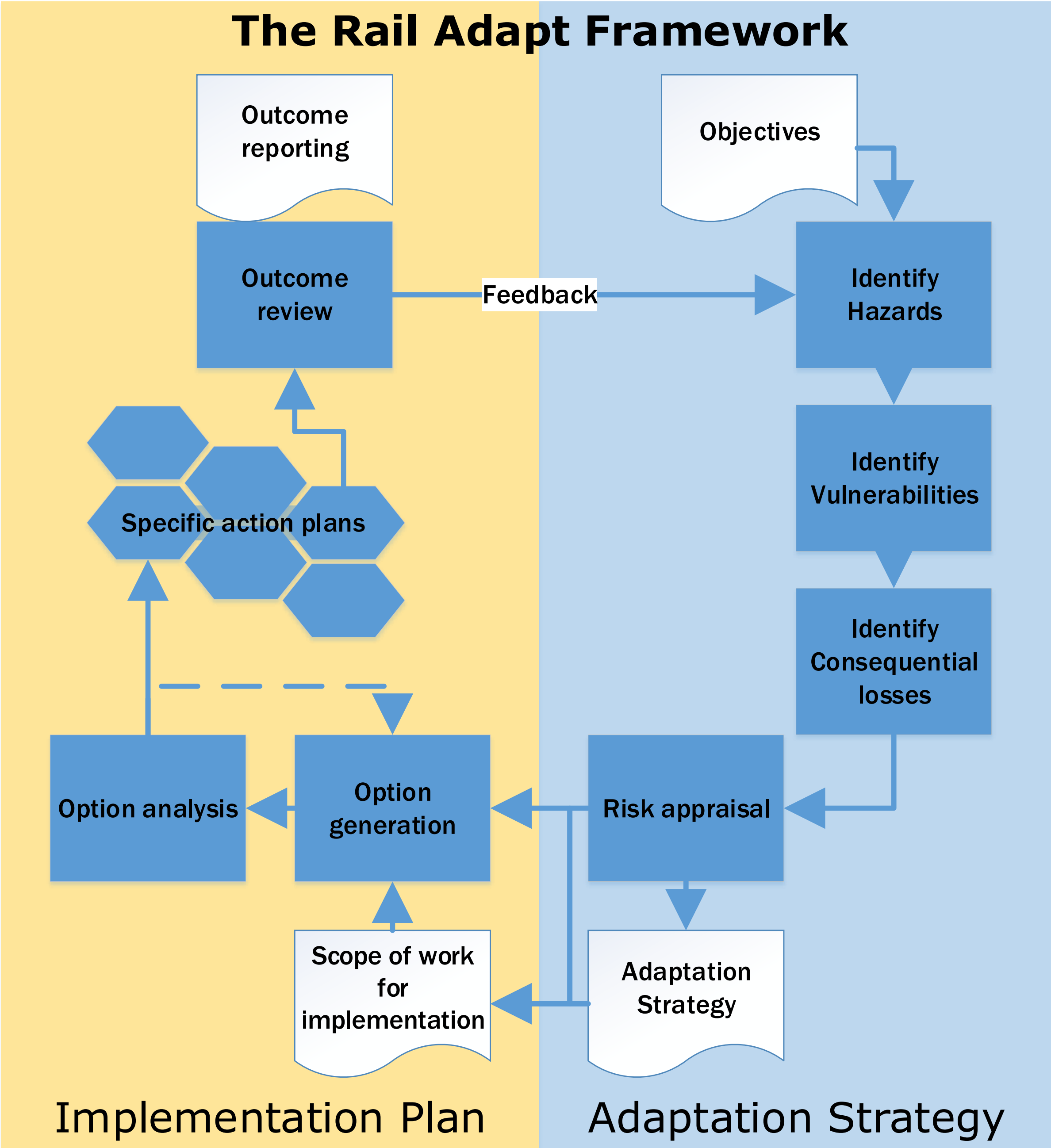
Corporate risk	Climate adaptation examples
Reduced asset condition and safety	Assets deteriorate more quickly due to changes in average climatic conditions; assets are more badly damaged as a result of more extreme climatic events.
Reduced network availability and/or functionality	Need for restrictions on the network to maintain safety; increased need for roadworks.
Increased costs to maintain a safe, serviceable network	Construction/maintenance/repairs/renewal required more often; more extensive construction/maintenance/repairs/renewal required; new (more expensive) solutions required e.g. designs and materials/components/construction costs.
Increased safety risk to road workers	Increased risk to construction and maintenance workers and Traffic Officers as a result of climatic change e.g. if need to work on the network more often; if required to work on the network during extreme climatic events or if climate change requires them to perform more 'risky' activities.
Increased programme and quality risks due to required changes in construction activities	More onerous design requirements; new technical solutions required with higher uncertainty, affecting project programmes and/or quality.
Current Highways Agency internal operational procedures not appropriate	Effects of climate change require new ways of working - changed or new business processes, new skills/competences.
Increased business management costs	Need for more staff; more frequent (expensive) incidents to pay for; need for more research into ways of coping with climate change.

After Highways Agency (2009)

The Rail Adapt framework contains two sections: (i) the development of an Adaptation Strategy and (ii) the Implementation Plan. This structure is based on the experience of transport administrations such as the Swedish Transport Administration (Trafikverket), the Finnish Transport Agency (FTA) and the PIANC World Association for Waterborne Transport Infrastructure guidance to ports. It is also aligned with the structure of ISO55000 and the PIARC World Road Association adaptation framework. Through experience, organisations have found that there can be too great a step between overall organisational objectives, that have potentially national or international aspects, and the individual adaptation actions that can be implemented in the short-term, which ultimately can lead to stagnation of the adaptation process. Therefore, the purpose of the Adaptation Strategy is to:

- help refine and focus the overall objectives into specific areas of maximum concern and benefit to the organisation;
- set the parameters such as time-scale over which they are to be implemented;
- set appropriate priorities.

The Implementation Plan then works within the scope outlined in the Adaptation Strategy to explore and develop specific actions and plans that can be implemented, and to report on the progress of these actions both internally and externally. This division in the framework is also useful for different elements of the business that may be involved at different stages, with implementation devolved to specific projects and managers.



2.2. Developing an Adaptation Strategy

As discussed in the previous section, the objectives for the Adaptation Strategy may be defined externally or internally by the organisation itself. They should reflect the high-level motivation, awareness and objectives of the organisation to improve preparedness and resilience to the impacts of climate change without unfounded assumptions. They may also reflect the experience of previous adaptation actions and feedback from existing projects or activities. It is critical that they do not focus purely on the most recent or most disruptive event(s) that may have occurred but rather drive an evidence based approach to holistic risk analysis. To do so then ensures that resources are focussed on the future challenges the organisation faces.

In developing the Adaptation Strategy, the framework suggests a risk-based approach following the recommendations of the Organisation for Economic Cooperation and Development in the development of policy (OECD, 2015b). This embodies a proportionate, flexible and iterative method to dealing with the uncertainties inherent in any decision making about the future of complex systems like economies, society and climate.

Adapting to climate change: European framework for action

In 2009 the European Commission proposed a framework for climate change adaptation action which has 4 key elements:

1. building a solid knowledge base on the impact and consequences of climate change for the EU;
2. integrating adaptation into EU key policy areas;
3. employing a combination of policy instruments (market-based instruments, guidelines, public-private partnerships) to ensure effective delivery of adaptation and
4. stepping up international cooperation on adaptation

The European Climate Adaptation Platform (Climate-ADAPT) aims to support Europe in adapting to climate change (EC/EEA, 2017). It helps users to access and share information on:

- Expected climate change in Europe
- Current and future vulnerability of regions and sectors
- National and transnational adaptation strategies
- Adaptation case studies and potential adaptation options
- Tools that support adaptation planning

Most organisations will have existing risk management capabilities, which will already have experience of identifying and managing risks associated with safety, security and business continuity. Risk associated with climate change should be added and included within these processes if they are not already present. Transport systems have multiple interconnected assets which have different lifespans, maintenance and renewal schedules; and critically different exposures to aspects of climate change. Therefore, risk management approaches must also have the capability to reflect this variety.

Risk can be defined as the combination of: a hazard, such as extreme temperature, rainfall or other aspect of climate change; the vulnerability or susceptibility of assets or services to this hazard; and, the consequence of these services or assets failing, to both the organisation, passengers, users and external stakeholders. It is important to distinguish these elements to allow for fair consideration of frequent but minor disruptive events alongside rare but potentially catastrophic events. It also enables other stakeholder perspectives to be considered. For example, the disruption to a line with a daily freight service may appear minor to an infrastructure manager but if that freight service provides fuel to an electricity generator or local transport services, chemicals for water treatment or access to a hospital, the result may be widespread disruption and much more serious losses. Identifying such dependencies and interdependencies is an essential part of the assessment process.

Interdependencies: indirect impacts on railway systems

The TRaCCA project task 4 conducted an in-depth study of the fuel supply to major electricity generating stations. The dependencies between a railway subsystem and an external system can be characterised by the flow or interaction of one or more of the following elements:

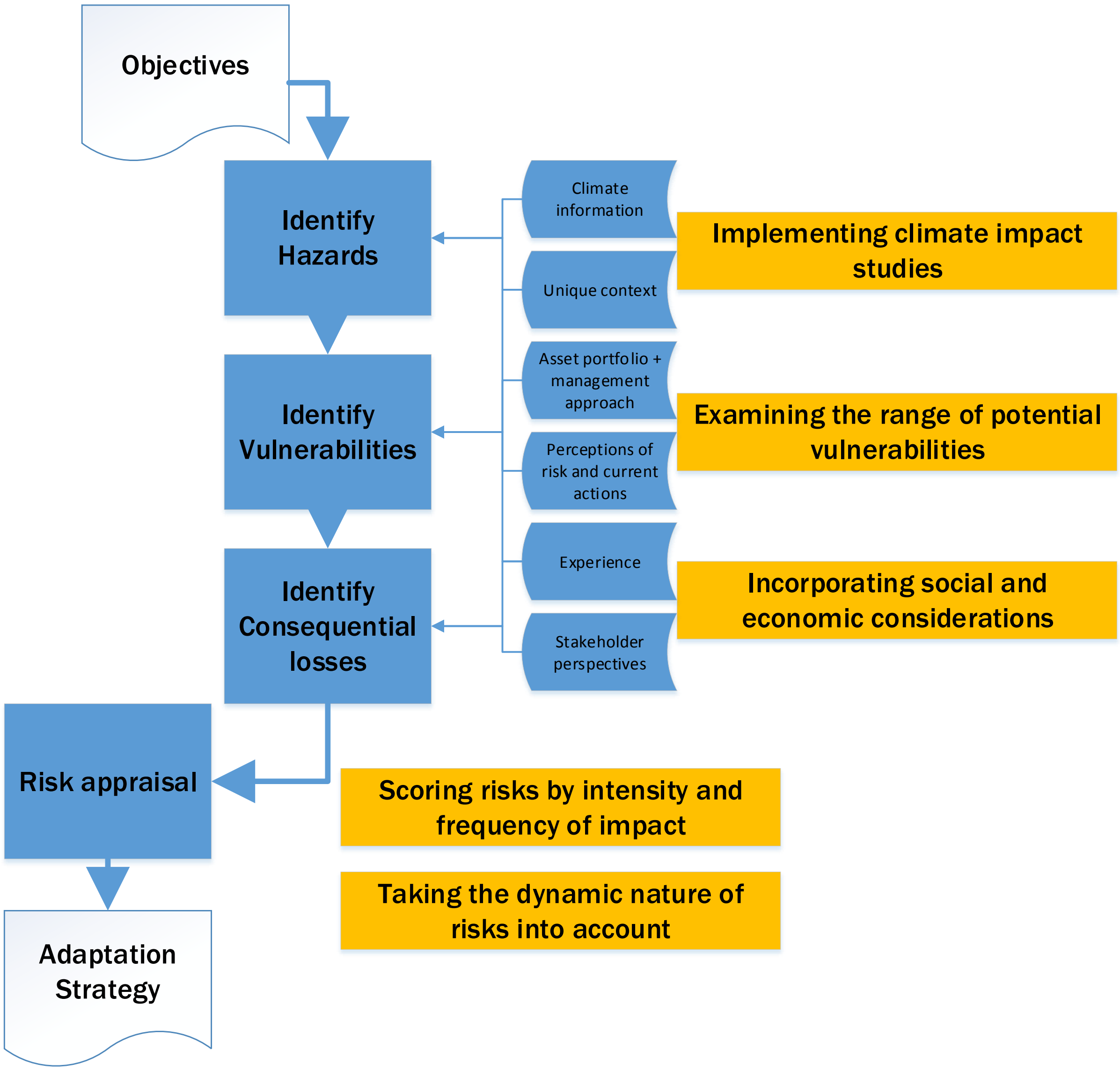
- People
- Materials and buildings
- Machinery or other devices
- Fuel and power
- Communications and data
- Other flows

A specific risk, for example flooding, has impact on these flows which can be direct or indirect. Direct impacts could be on track materials, rolling-stock machinery and staff or passengers.

Indirect impacts of flooding on the railway system included:

External systems	How flooding would affect the external system	Potential impact on rail in the case study
Electrical Power	Flooding of power sub-stations causing shutdown. Loss of power could also disable other infrastructure systems	Power shortages for traction, signalling, depots and stations. Widespread loss of power would affect machinery, comm/data of freight clients (including ports) which would halt operations
External Water related systems (flood defence, sewerage, drainage and ground water)	Flooding overloads drainage capacity Disruption of clean water supply Damage to bridges and embankments	Staff shortages because of flooded homes. Flooded stations, lack of water, flooded toilets. Damage to railway track, bridges etc.
External transport systems	Road flooding and closures	Staff and passengers cannot reach depots/stations. Machinery cannot be moved for rail works.
External Fuel Supply	Flooding would affect fuel supply to the railway	No fuel for railway operations

After TRaCCA (2016)



Rail Adapt Adaptation Strategy process

This assessment process leading to the Adaptation Strategy is outlined above with the identification of hazards, vulnerabilities and consequences feeding into the overall risk assessment.

2.2.1. Hazards

The process of identifying meteorological, climatic, and other hazards is one that may start with a review of historical experience to indicate the types of incidents that are of primary concern. However, as climate change is likely to change both the types and frequency of events that occur, it is therefore important to fully explore other potential future hazards and opportunities for savings that may occur because of a reduction in current hazards. This type of climate information may come from national meteorological or other services, or through international efforts such as IPCC AR5 (see Appendix 6.1).

Understanding regional climate

There are good sources of information and understanding about potential climate changes for all areas of the world. Many local meteorological services have produced models and assessments of likely future climate for their areas. These compliment major international studies carried out and complied as part of the IPCC process. The latest IPCC reports (the 5th assessment) now cover the underpinning climate science, adaptation (impacts and how they can be addressed) and mitigation (reducing GHG emissions). Within the IPCC adaptation report there is a section specifically on regional aspects (part B) which provide the best available information about likely climate changes to local areas and the impacts these are likely to have on different natural and human systems, such as transport. Further information is provided in Appendix 6.1 from a variety of sources.

For example, in the IPCC adaptation report chapter 24 (Asia) an example of how improving drainage in Mumbai could reduce extreme flood losses by 70% is given. It is also noted that in extreme events transport and power infrastructure can be disrupted across large areas. However, these failures are rarely due to a single cause, instead being linked to complex social, political and environmental factors. It is therefore important to understand that climate information is only one part of the solution in developing an adaptation plan.

Typically, organisational asset management is already dealing with environmental impacts on assets and operations, and climate change can be thought of as a systematic change in the forecasts for what those environmental factors' hazards will be. Therefore, it is appropriate for organisations to agree a consistent approach for considering climate change across different business or geographical areas. This might include high-level agreement on climate change scenarios that the organisation plans for and accepts in its internal business cases and investment regulations.

Understanding and interpreting such information, including the uncertainties inherent in any future prediction, for the context of the railway may require expertise both in railway systems and of meteorology. It is therefore recommended that expert knowledge be sought to ensure that the climate data is properly understood and utilised. It is important that the climate information reflects the relevant time frames being considered, for example the lifespans of assets being managed and the planning cycles of the organisation but that these latter timescales do not limit the consideration of long-term hazards, such as sea-level rise, on long-life assets such as bridges and embankments. Examples of how this has been done in a variety of other European sectors can be found though the Climate-ADAPT portal (EC/EEA 2017).

2.2.2. Vulnerabilities

How climate and weather hazards impact on the railway, including assets, operations, services and passengers, is a complex area which is not fully understood. In some circumstances, it may be clear that there is a direct relationship between a problem, for example the failure of points machines, and meteorological conditions, such as freezing temperatures. However, in many cases railway disruption has multiple possible causes or is caused by a combination of factors. Assessing vulnerability to specific hazards, or combination/concurrent events, is therefore probably the most challenging step in the assessment process (de Buck, 2016).

Although challenging, the adaptation-planning process can be undertaken even with imperfect information, and a priority of the Adaptation Strategy can be to identify areas where additional data and information are required for future iterations. It may be initially sufficient to define whether vulnerability is high, medium or low (a ‘traffic light’ system) for different geographical locations, types of asset or services, based on

Understanding the links between weather and disruption

The rail industry has huge knowledge embedded in the experience of staff about where problems can be expected to occur in bad weather. However, much of this knowledge is lost when staff retire or leave and therefore capturing and passing on such understanding is vital. One method for doing this is through gathering good quality data on disruptive events, and the real causes of such events, linked to good meteorological (and other scientific and engineering) understanding.

Diagrams such as those produced in the TRaCCA project (available through the RSSB Spark portal) can help to express the links between extreme weather and specific problems highlighting where specific actions can be taken and where gaps in knowledge exist. Various information about these risks is reproduced in Appendix 6.2

historical information. It may also be possible to collaborate with other similar organisations internationally to share information and experience about vulnerabilities, particularly where there are potential analogies with future climate.

Developing new information to address knowledge gaps

In Japan heavy rain and mountainous terrain make debris flow the single largest geo-hazard, around 1/3 of events, for Japan Railway group. It was recognised that the general rainfall thresholds being used to give warnings were not a sufficient control and further knowledge was required to focus warnings into at-risk areas. A slope risk evaluation model was commissioned and developed by the Railway Technical Research Institute Japan which enabled prediction of when and where debris flow is most likely to occur, thus enabling better risk assessment to be factored into warnings.

Engaging with other sectors

Issues of dependency (e.g. road access and fuel supply for rollingstock) and interdependency (e.g. electrified rail delivery of fuel for electricity generation) make cross-sectoral working with stakeholders critical to good adaptation planning. Sectors such as Energy, particularly electricity supply, are conducting adaptation planning through projects such as the ETI Natural Hazards review (ETI, 2017).

International Analogues

Due to differences in regional climates, different regions around the globe will have varying levels of experience in dealing with specific vulnerabilities to the rail network caused by extreme weather. For example, southern Europe and Africa may have more knowledge on managing extreme heat impacts whilst the Nordic regions and Russia would have greater experience of extreme cold. In a changing climate, the type and frequency of extreme weather events experienced in a region may be significantly different in the future compared to the present, with new vulnerabilities emerging that local networks have limited experience of managing. It is therefore beneficial to draw upon international analogues, where a region may increase their preparedness for projected weather hazards by learning from existing experience of the same hazards in another region. What vulnerabilities do they face? How are they measured or monitored? How do they manage these vulnerabilities? What adaptation or resilience solutions exist?

Such experience can considerably increase a region’s ability to pro-actively adapt their railway system to manage vulnerabilities, as well as planning response should a failure occur. When looking to establish international analogues, the analogous region should not only have similar climatic conditions to future projections for the beneficiary region, but also a similar rail network to ensure that the learning gained can be applied as directly as possible. Learning can be disseminated through a variety of formal or informal mechanisms. Mutually beneficial knowledge-sharing partnerships could be agreed between railway organisations in different regions, or as part of a broader network for the sharing of vulnerability experience and adaptation best practice. More informally, information could be exchanged directly between individual experts within railway organisations.

A methodology for identifying and establishing international analogues is outlined as part of Task 2 of the TRaCCA project which focused on compiling a compendium of adaptation best practice potentially beneficial to the GB rail network. This has also been published in the academic literature (Sanderson et al, 2016).

Where the organisation has primary concern for infrastructure assets this vulnerability will link directly to the asset management strategy. Asset management is already a highly developed area and many of the processes and concepts are directly transferrable to the area of climate change adaptation. For example, the ISO 55000 family of international standards provide a wealth of reliable advice on undertaking effective asset management. Specific guidelines for railway organisations on the adoption of ISO55001 are also published by the Union of International Railways (UIC, 2016) as part of their support to the global rail sector.

Good asset management recognises that individual assets may perform the same function equally well but that there may be underlying differences in asset design, age, or current condition. This has a direct impact on their susceptibility to different hazards at different locations and this will need to be recognised in the vulnerability assessment. In some cases, very limited information may be available about some assets and an organisation may wish to consider robust data gathering as one aspect of their Adaptation Strategy in order that future iterations can make more informed decisions.

There may also be ongoing current projects or developments within the organisation that will by consequence reduce vulnerability, and these should be factored into the assessment. However, it is also possible that new systems and assets themselves introduce vulnerabilities which are new to the organisation. For example, renewal of a railway line may reduce its vulnerability to flooding. However, if the line is simultaneously electrified, vulnerability to windy conditions will increase due to exposure of the catenary and dependency on the electrical supply will bring new vulnerabilities to services.

2.2.3. Consequences

Once the future likelihood of climate hazards and the potential vulnerabilities of your organisation’s systems have been identified it is also necessary to consider and quantify the potential consequences of failure of those systems both to the organisation and externally. As mentioned previously the incorporation of passenger, freight user and external stakeholder perspectives on these consequences is recommended so that the focus of improvement is not purely internal, which may then miss important dependencies and interdependencies.

Case Study: Egypt – Egyptian National Railways (ENR)

Climate change impacts on Egyptian railways

Egyptian National Railways (ENR) is a governmental authority, affiliated to the Ministry of Transport, in charge of operation, maintenance and upgrades to the railway network in Egypt. ENR has an extensive network of about 50 lines and 9560 track km, 60% of which is concentrated in the Nile Delta and along the Nile Valley.

Sand Drifts

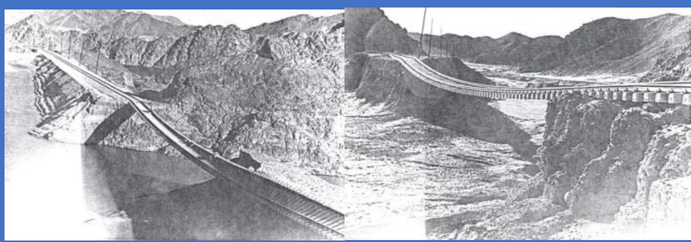
Rail lines passing through desert areas can benefit from an aerodynamic study of sand drifts across the track. Sand accumulates at varying levels at different parts of the route, especially in deep cut sections, and can stop traffic until the sand is cleared. Sand also causes erosion at switches and crossings, engine defects in rolling stock and passenger discomfort. Protective measures such as blowers and filters are required to control the sand.

The Abou Tartour - Qena line was constructed in the 1990s with a length of 450km. Through springtime in the Western Desert, the railway is subject to severe wind storms loaded with large quantities of fine to medium sand that accumulates on and around the track. Part of the line crossing an area of large sand dunes is also subject to these conditions.

During 1996-1999, an aerodynamic CFD model (called SADU for Sand And Dune Utility) was used to study the wind distribution and regimes, solving 3D unsteady 2-phase flow, over the route and predict localised wind roses taking into consideration the topological effects of the surrounding area. The model helped in defining the amount of sand drift in different directions, and thus the amount of sand accumulated over the line. Potential aerodynamic modifications to the slopes of the embankments were modelled, to obtain optimum slopes that create the minimum sand deposition on the line. After implementation, the embankment modifications performed efficiently and now protect the line from being submerged by sand.

Storm Water

The Qena- Safaga line was constructed in the 1980s, with a length of 230km. Large sections of the line pass through a chain of mountainous regions. This part of the country faces periods of very rough winter weather, resulting in severe thunderstorms with large amounts of flood water flowing from the mountains. The track is protected by multiple anti-flooding structures in the form of multi-vent or multi-circular pipe concrete culverts. Again, there is usually annual destruction and wash out of embankments across several parts of the line, which usually results in long spells of interruption to the operation of the railway as well as causing severe financial losses. The existing railway line suffers from flooding due to its path through the valleys. It has around 110 culverts, but the Badwy people use them as residential places.



The torrential rains in Matrouh and the northern coast on October 2009 caused the erosion of the dust under the Matrouh railway with a length of 36m and a height of up to 2m, at 10 km east of Marsa Matrouh city, causing the Alexandria - Matrouh train to be disrupted for more than 6 hours.

Sea Level Rise (SLR)

Sea-Level Rise can increase the hazard potential for the North coastal populations, infrastructure, and investment. In low-lying deltas, SLR could be up to 175cm by 2100. The Nile Delta is also threatened by land subsidence, with some studies finding subsidence rates could reach 0.5cm/year, and by 2100 a projected minimal incursion of the sea could reach 30 km inland in the north-eastern Nile Delta.

Case Study: USA – Capitol Corridor Passenger Rail

Sea Level Rise Vulnerability Assessment

The Capitol Corridor intercity passenger rail route, connecting the greater Sacramento metropolitan region to the San Francisco Bay Area, is already vulnerable to flooding from extreme storms and with such events expected to become more frequent in future early adaptation planning is critical. Even a small degree of SLR can present a great flood risk to vulnerable areas along the route.

Completed in August 2014, the Capitol Corridor Joint Powers Authority (CCJPA) conducted a vulnerability assessment for sea-level rise (SLR) along the route. This assessment identifies various types of vulnerabilities (physical, functional, governance, and information) for assets in six focus areas in different geographic and land use settings: Suisun/Fairfield Station, Martinez Station, Point Pinole, Oakland, Oakland Coliseum Station, and Santa Clara/Great America Station.

The project initially stemmed from the San Francisco Bay Conservation Development Commission's (BCDC) Adapting to Rising Tides (ART) project. The assessment methodology follows the ART assessment process model. The assessment starts at the Scope & Organize stage and proceeds to the Plan stage with suggestions for adaptation responses. A literature review of papers and reports on climate change and sea level science and predictions, especially those that focus on California or the rail system, was undertaken prior to the assessment.

A methodology including Geographic Information Systems (GIS) analysis and consultation with asset managers was employed to evaluate the vulnerability of crucial assets in these hotspots, including railroad tracks, bridges, the signal system, a maintenance facility, and train stations that serve the Capitol Corridor route. Within the six focus areas, the risks of permanent inundation, temporary flooding, and shoreline erosion comes from nearby sources or bodies of water. Liquefaction can also damage rail assets where saturated soils that are loose or sandy will exhibit the characteristics of a liquid when shaken long and hard enough, which could cause structures built on top of the soil to distort and collapse. As the groundwater levels rise due to SLR, liquefaction zones are expected to increase in overall extent.

Key Asset Vulnerabilities

- The rail system is linear and lacks redundancy, therefore disruption to one sections disrupts the entire system.
- The signal system is also critical to operations, and can result in temporary delay or complete shutdown of the line.
- Some stations are physically vulnerable to SLR due to their location or functionally vulnerable due to their reliance on external power.
- Oakland Maintenance Facility is a crucial asset vulnerable to SLR and liquefaction due to the location and sensitive below-grade components.
- The complex ownership and management structure for assets may complicate adaptation and resilience plans.
- There is a lack of detailed public information about railroad infrastructure (tracks, signal system, and bridges) owned by Union Pacific, with no formal information sharing agreement between Union Pacific and CCJPA.

As a result of the assessment, CCJPA now has a better understanding of the vulnerabilities of rail operations and service to the impacts of SLR, from more frequent and severe flooding events to increased rates of shoreline erosion. The assessment will inform the identification of appropriate SLR adaptation responses from planning and asset management perspectives, including addressing governance and information vulnerabilities by working with stakeholders and community partners.

In addition, the inclusion of external stakeholders in assessing consequences (and therefore risk) enhances organisational reputation in the wider community and enables those stakeholders to better understand and cooperate with you during periods of disruption. For example, engaging in a joint, multi-modal, transport sector risk analysis within a city region may enable a collaborative approach to adaption planning and highlights the importance of transport resilience to stakeholders thereby potentially gaining support for adaptation actions.

The quantification of consequences is most easily done for direct financial losses; however, it is also recommended to consider the environmental and social consequences of disruption. For example, where a bridge fails this may be the only link of a community to other areas and therefore critical to their wellbeing, fuel or food supplies or access to healthcare. It would therefore be appropriate to consider this loss of higher consequence, because of the socioeconomic impacts, than purely the revenue that may be lost directly to the organisation (Jaroszweski et al, 2010, 2015). Such elements may already be required as part of the Environmental Impact Assessment for new infrastructure projects but should be consistently applied to all parts of the network.

Even where the direct costs of repair can be estimated there may be hidden elements that should be considered. For example, where flooding occurs there may be significant cleaning costs associated with contamination from sewage; or an increased susceptibility of equipment to fail again in future or a reduced asset lifetime after repairs.

Risk Representation

When designing new assets, or adapting existing infrastructure to cope with the projected impacts of climate change, design specifications can be based upon the idea of probabilistic ‘return periods’ for extreme weather events. In this case, risk is represented as the estimated frequency of experiencing an event of a given magnitude within a defined time period. For example, a 1:100 year flood would refer to a threshold only expected to be exceeded once in one hundred years on average. Assets can therefore be engineered so that they should be resilient to extremes projected to occur during the asset lifetime.

‘Return periods’ can be estimated by calculating a probability distribution of observed weather events. However, such an approach assumes stationarity in the climate system. Climate change is expected to increase the frequency and severity of extreme weather events and, as such, the threshold of a 1:100-year flood in 2080 may be significantly higher or lower than today. The probability of exceeding a certain threshold is therefore nonstationary, which has the management implication that existing assets built to a certain standard in the past may now be more at risk. Planners of new assets must consider the evolution of the climate system during the expected asset lifetime. ‘Return periods’ by their nature are average values and should be used as an indication rather than a deterministic measure of risk (Read and Vogel, 2015).

Houston in the USA, for example, experienced three "500-year" flood events in three years. This is related to climate change because higher temperatures mean that there is more water in the atmosphere, and the probability of these heavy rainfall events has increased. Therefore, these are no longer "500-year" floods, the ‘normal’ level has shifted and will continue to do so.

2.3. Risk Appraisal

Having assessed the available information on future climate hazards, vulnerabilities of the organisation and the consequences of service failure, these can be combined into an overall risk appraisal. The purpose of this appraisal is to consider what the most significant risks to the organisation are, and which must be addressed as a priority to achieve the objectives set out at the start of the process.

This process is likely to identify a variety of significant long-term impacts, which perhaps will develop slowly, and also immediate concerns about the impacts from extreme weather events that have occurred recently and may reoccur. It is important that both be given due consideration within the priorities and that short-term priorities do not block progress on potential long-term adaptation.

ARISCC (2011) guidance for infrastructure managers

The ARISCC project, supported by UIC, produced a guidance document for Railway Infrastructure Managers for integrated natural hazard management comprising the following elements:

1. Weather Information, Weather Warning and Weather Monitoring

2. Recording, documentation & assessment of past weather events

3. Mapping of natural hazards which can potentially impact the railway infrastructure (including the locations of possible impacts)

4. Monitoring and documentation of the status of infrastructure assets (e.g. bridges, drainage system, tracks, earthworks, signalling system…) including protective measures

5. Assessment of the vulnerability of railway assets with respect to the different natural hazards

6. Assessment and management of the risks associated with different natural hazards – risks to asset integrity, railway operation, environment, railway image and safety risk

7. Assessment of future weather and climate related natural hazards by using regional climate models

The outcome of this risk appraisal is then an Adaptation Strategy for the organisation that prioritises the risks which need to be addressed in order to achieve the objectives set both internally and externally for resilience and preparedness. This Adaptation Strategy forms the first part of the scope of work for the Adaptation Implementation phase.

2.4. Financial Options Appraisal

Any adaptation strategy must take into account the financial costs and benefits of interventions considering:

- the railway itself,
- the users of the railway,
- the governance context
- wider national government policy.

There are a number of points of importance:

1: the cost of adaptation may be mitigated through an asset management strategy that integrates adaptation with business as usual rather than regarding it as an optional or a separate stream of activity

2: while technically possible from an engineering perspective, the cost of delivering an 'always available' weather proofed railway may well exceed the benefit to individuals and society as a whole from doing so and may still impart unacceptable risks to railway employees and others

3: there will be a financial crossover point where the cost of additional adaptation and/or resilience becomes disproportionate to the additional benefits derived, it is important to understand where this arises

4: a focus on whole life value, taking account of the range of operating conditions of the railway under consideration will lead to a solution which offers best value over time

The UK Treasury 'Green Book' (HM Treasury, 2016) five case investment appraisal methodology provides a helpful starting point for this, it is used across public sector investment appraisal in the UK and adopted (in varied forms) by many other governments. The five cases are:

- Strategic – what are the opportunities arising from the investment
- Economic – what makes this value for money, why is this good for the economy and society
- Commercial – what are the commercial implications e.g. property, ownership, rights and obligations arising from the opportunity

- Finance – what will be the costs, how will they be paid for, how will borrowings be repaid
- Management – how will the process be managed and does the organisation have capacity

In certain circumstances the framework can be extended to consider the issue of public safety as well as public value and as safety is a key aspect for railway undertakings this will be a factor in addition to environmental considerations. While a full train, propelled by electricity, is considered the most energy efficient means of travel, adaptation should take account of the carbon cost incurred (and avoided) by the increased use of rail transport.

Three of the 'Green Book' case considerations (strategic, commercial, management (or operational) capacity) are covered elsewhere in the framework so the primary concerns here are the economic and financing questions.

The first of these is concerned with the overall business case, what will it cost, what will be the benefits, when will they be delivered. This could essentially follow the traditional pattern of cost/benefit analysis (CBA) but needs to account for not just the narrow concerns of railway revenue versus railway costs but the impact on the wider economy served by the railway. There will be losses and gains consequential on the availability or otherwise of the railway and these need to be understood and accounted for in the overall, systemic, financial modelling (Beckford, 2012). The crucial factor is to understand the extent of interdependence between the railway and the wider economy. For example, when a sea wall collapsed in 2014 the UK region effected lost one of two major arterial transport routes and its only significant rail link, with estimated resultant economic losses of £1.2bn.

In order then to comprehend the CBA case the organisation needs to understand the interdependency between railway and the wider economic system. This requires a resilience analysis, an outline of which is presented in Appendix 6.3.

It is likely that any organisation providing funding or financing for a railway will be concerned with similar questions although the source of the monies will influence the particular interest, i.e. commercial providers are likely to be more focused on financial investment return whereas development banks will have an interest in both economic gains and social impacts.

While individual governments adopt their own investment appraisal methodologies, development banks such as EBRD are willing to provide adaptation finance under certain conditions. In considering adaptation oriented projects they are concerned to ensure that the timing of climate change impacts has been assessed and that vulnerabilities have been recognised and prioritised appropriately. It is clear that as climate change impacts are being assessed against a dynamic environment, such projects need to be concerned with all three uncertainties of likelihood, impact and cost – and it is critical to make those uncertainties transparent to funders. It should be possible, even within a project where adaptation is integrated, to recognise any particular costs or actions directly associated with climate change impacts. The costs and the benefits should both be considered against the life cycle of the assets concerned and the development over time of the climate change risk.

Similarly, insurers and re-insurers will need reassurance not only about the technical feasibility of adaptation but also about the resilience of the railway in all its dimensions, including resistance to failure (robustness), contingency planning (redundancy) and its ability to recover after disruption and return to revenue service.

In its analysis of the cost of environmental regulations, the World Bank (2012) concluded that, at the level of individual companies, costs are typically modest because they can adapt and innovate. They conclude that there is no evidence that environmental regulation systematically hurts profitability but advise that lower income countries should focus on adapting and implementing existing technologies. Such adaptation is facilitated by developing regional and global partnerships to exchange information and experiences. Such sharing of knowledge, and resilience assessment outlines such as presented in Appendix 6.3, will enable railway undertakings to meet the requirements of development banks for project applications to have appropriate climate change screening.

Infrastructure investment remains vital to underpin sustainable economic growth and development. More investment is required to meet the Paris Agreement's mitigation and adaptation objectives, with infrastructure and technology transformations needed to shift economies onto low-emission, climate-resilient pathways. OECD (2017) has explored how governments might better align short-term investment strategies with long-term decarbonisation and resilience goals with a focus on the energy sector as an indicative assessment of progress. The rail sector can engage governments and encourage such alignment through adaptation strategies which address these larger goals.

Case Study: USA – TCRP A-41 Research Project

Improving the Resilience of Transit Systems Threatened by Natural Disasters

Extreme weather events and other natural disasters threaten the operations and the capital assets of transit systems across the United States. As part of TCRP (Transit Cooperative Research Program) A-41, a research project funded by the Transportation Research Board, three main work products were produced. All products are available at Alan M. Voorhees Transportation Center (2017).

Improving Transit Resilience Guide

The guide has been designed for multiple users, but with a focus on the "middle" managers that may be most likely to lead or facilitate resilience adoption in their agency. For those new to resilience and even more advanced practitioners, the guide presents an actionable, step-wise approach to help an agency meet the challenges of extreme weather and climate change. It is designed to encourage agencies of all sizes and states of preparation to define their own circumstances and capabilities to make the transition from "everyday" practices into a forward-looking, risk-recognizing and comprehensive approach to resilience. The guide is framed around the concept of resilience adoption across the many "domains" of transit agency business where resilience practices can be incorporated.

Improving Transit Resilience Database

The Improving Transit Resilience guide references and describes a variety of useful case studies, process aides, guidance documents, analysis frameworks, and other resources available to practitioners as they take steps to improve transit resilience at their agencies. Each resource profiled in the guide and many more, are included in the online Improving Transit Resilience database. A Resilient Transit search tool is provided to explore the resources in the database. Users can also contribute further Resilient Transit Tools and Resources to the database.

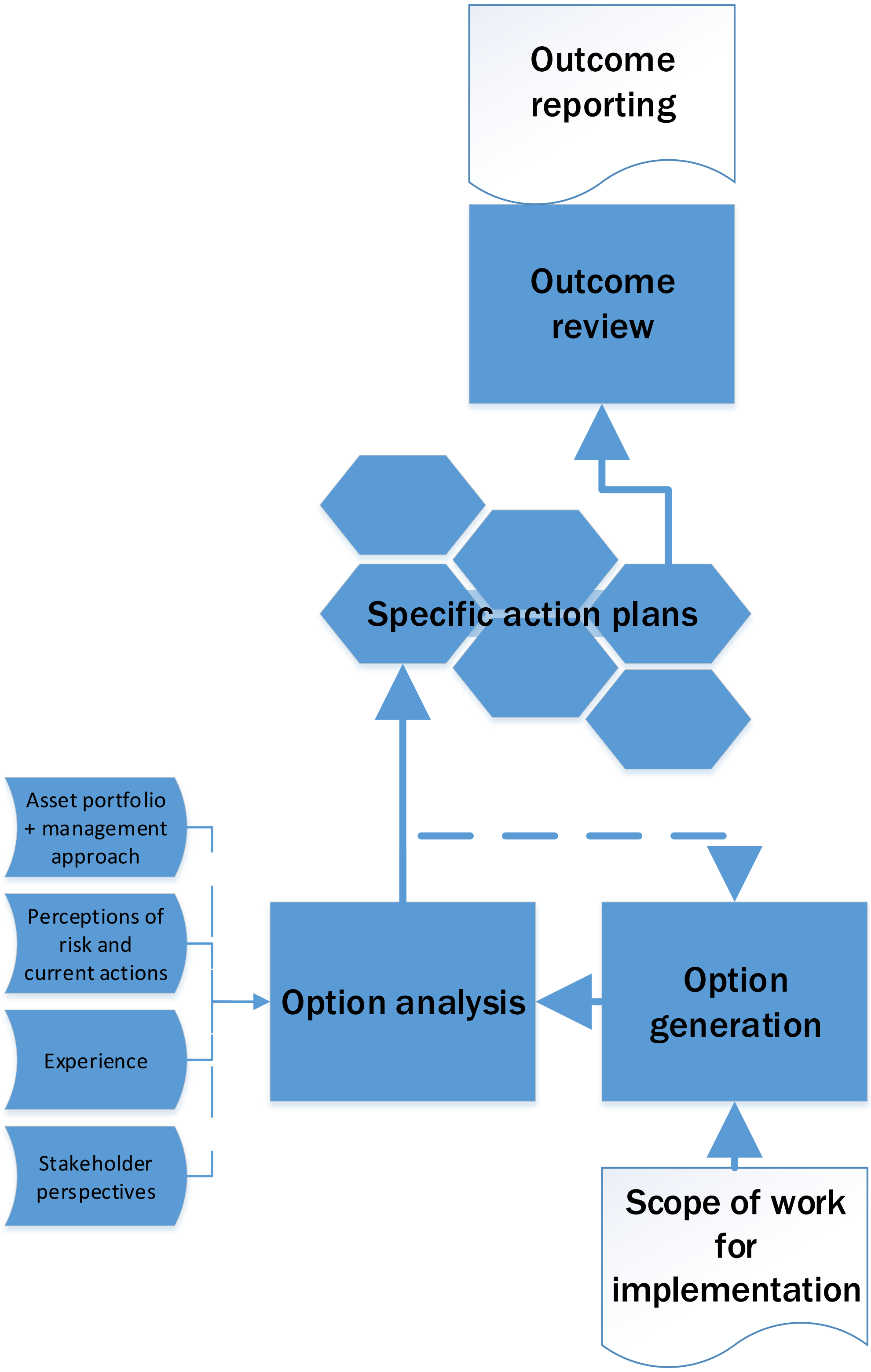
TRB-A4 Final Report

TCRP A-41 was initiated in 2015. The project included an extensive literature review and practice scan, 17 detailed transit agency case studies that showcase leading practices in resilience adoption across a wide spectrum of transit agency organisational structures/sizes/hazard profiles/regions, a workshop to test the proposed framework for the guide, and the development of the guide itself, with its accompanying website and database of tools and resources. Case studies and tools from outside the transit world were developed or adapted, to provide more context.

The TRB panel provided insights and direction, and the study team continued integrating new information throughout the project while also distilling and winnowing existing information into concise form. The project also included extensive interaction with the American Public Transportation Association (APTA) to develop a way to incorporate resilience into APTA standards and guidance, as a long-term tactic to institutionalise resilience practices within transit agencies.

The final report (Alan M. Voorhees Transportation Center, 2017) summarises the major elements of the research effort, with references to full documentation. The report also identifies additional research needs that have been identified during the study.

3. Implementing Adaptation Plans



Rail Adapt Implementation Plan process

An organisational Adaptation Strategy provides the starting point for implementation by setting out both the objectives to be achieved and the priority risks to be addressed. Alongside this will be the constraints of time and budget that the organisation will impose.

The concept of a 'budget for adaptation' is one that causes widespread concern in organisations because of financial constraints. As stated in the introduction, the Rail Adapt vision and framework does not foresee a 'special project' or new undertaking for rail organisations, which therefore requires a new budget, but instead that **adaptation is a normal function of business, bringing together elements which may currently be disparate or separated to improve business outcomes**.

That is not to say that investments will not be required to achieve improved resilience of services, but these will be justified through the normal business decision-making process of achieving strategic objectives of the organisation, including management of costs and assets. For example, in deciding to invest in new assets the adaptation of those assets over their design life will now be an integral part, not an additional cost, and therefore a potential long-term saving on repair and recovery costs. In addition, as outlined below, **addressing risks early and in a structured manner may require no additional cost because risk mitigation measures can be factored into routine maintenance and renewal**.

3.1. Option generation and assessment

Critical to the success of Adaptation Planning and Implementation is the identification of options to address the risks identified in the Adaptation Strategy. A genuine assessment of options is vital to achieve the best outcomes in the most effective way and to avoid maladaptation, which is the development of short-term solutions that do not match long-term requirements. For example, to replace a structure that has failed due to extreme weather with another of the same specification may give rapid restoration of service but may miss an excellent opportunity to reduce long-term risk if that weather hazard is increasing in severity or likelihood. Other long-term objectives may include the reduction of carbon (emitted and/or embedded) and the improvement of safety. It is sometimes argued that after disruption the reinstatement to previous standards is mandated, for example by emergency management statutes, but this can be a form of maladaptation and should be questioned. After Storm Sandy, US rail and transit agencies successfully lobbied government that FEMA rules on reinstatement should not be applied because for critical transport infrastructure the need to 'build better' for the future was paramount.

The scope of work for implementation generated from the Adaptation Strategy, will define priority risks to be addressed. However, it will also show, through the risk appraisal that was undertaken, whether these arise from a change in the hazard, from the vulnerability of service, from

Building railway transport resilience to alpine hazards

As part of the EU ENHANCE project – partnership for risk reduction, a series of 10 case studies were undertaken including one with ÖBB Infra, the Austrian Railway Infrastructure company.

To protect their railway infrastructure from Alpine hazards, the ÖBB engages partners to jointly plan and implement resilience measures. The core of these partnerships lies in information exchange and cost-sharing. It includes formal, standardised processes fixed in regulations, as well as informal elements and ad-hoc negotiations (Kellermann et al, 2015).

The entire ENHANCE project final report is also available (ENHANCE 2016) developing and analysing novel ways to enhance society's resilience to catastrophic natural hazard impacts.

the consequences of disruption, or a combination of these. This understanding can also be valuable to the generation of options to address these risks. For example, if asset vulnerability is the basis of the risk then remedial engineering interventions may be appropriate. **In contrast, if a growing population is exacerbating the consequences of failure then options to increase capacity with renewal alongside improved resilience may be more appropriate.**

As with the risk analysis, the generation and assessment of adaptation options will likely benefit from external stakeholder input. Stakeholders may be able to actively support adaptation proposals through complementary activities because of a greater understanding of the objectives being achieved. Equally, your organisation may be able to facilitate other stakeholder objectives through your actions at little or no cost, but which achieves better community value. For example, where flooding of rail assets is a problem the source of the water may not be directly controlled by the railway but by neighbouring landowners. A shared approach to water management may minimise costs for everyone and achieve a better relationship in the long-term.

When considering the options to address a specific risk it is it also important to recall that there are many valid approaches to achieve resilience. These can include:

- Engineering solutions
- Operational planning
- Organisational enhancements

All of which are underpinned by the development of knowledge about climate change, resilience and adaptation practices more widely. Such approaches need to consider long-term preparations as well as short-term and even immediate responses to disruptive events such as the provision of good quality information to service users and passengers.

Within Engineering solutions one option is to make structures or services more robust, and therefore resisting failure under more extreme conditions. Rerouting lines or renewing assets to a higher specification are other solutions. Further options that may be considered include back-up facilities, either permanent or temporary (along with plans for their deployment) to provide redundancy and / or plans and capability to repair the system rapidly in the event of a serious failure. Operational options may include providing local accommodation for staff so that they can avoid journeys to and from work in difficult conditions and therefore avoid staff shortages. In some circumstances, even prolonged disruption may be deemed acceptable from a financial loss perspective but intangible costs such as damage to reputation, safety and political acceptability should not be disregarded.

Such alternatives are often paired with improvements in hazard (weather) forecasts and warnings of disruption, which allow time to prepare and put plans into action. These forecasts may be done internally but may also be part of a strategic partnership with external organisations, for example where a meteorological organisation provides specific warnings of weather conditions at a location or regionally so that preparations by the railway can be undertaken. Such preparations may also require collaboration with other services where there are shared risks or dependency of service.

The MOWE-IT project developed guidebooks for each transport mode with guidelines and recommendations for reducing the impact of weather on transport operations (MOWE-IT, 2014). The project aim was to identify existing best practices and to develop methodologies to assist transport operators, authorities and transport system users to mitigate the impact of natural disasters and extreme weather phenomena on transport system performance. The guidelines were structured into actions for Before, During and After events based on the experiences of rail undertakings through a series of documented case-studies on Heavy rain, Storms and Winter conditions. These guidelines are reproduced in appendix 6.4. In a separate analysis the TRaCCA project produced factsheets on managing Winter conditions, Flooding and Heat (TRaCCA, 2015a) which are reproduced in appendix 6.5.

Case Study: Russia – Russian Railways (RZD)

Asset Management and Extreme Weather Event Response

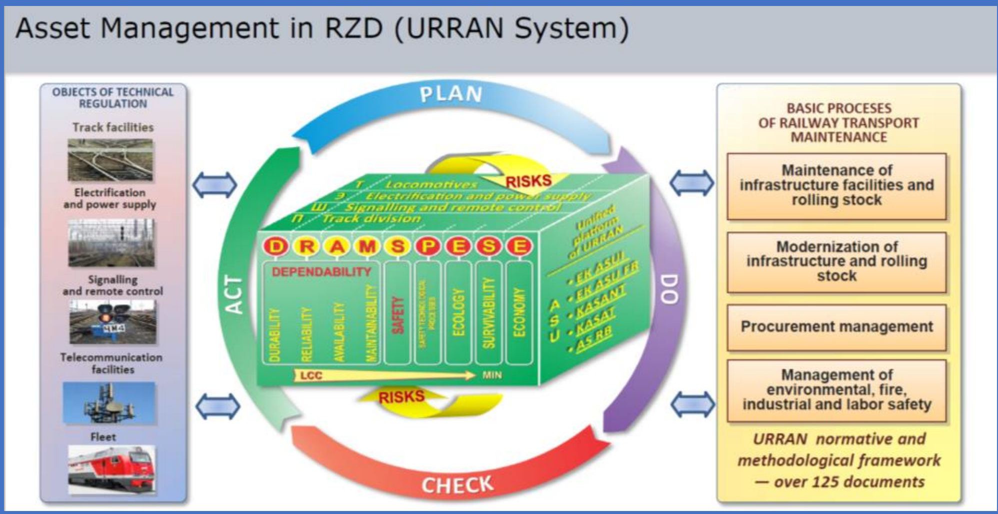
Russian Railways

Russian Railways (RZD) manage rail infrastructure and operate passenger and freight train services in Russia. With over 100,000 track km, the Russian rail network is very extensive and therefore exposed to different climatic and geographic zones which present a complex array of hazards. Ice and snow on overhead lines, track flooding from heavy rainfall, falling trees during storms and high winds, and fires during summer have significant impacts on rail operations. The key priority is thus efficient asset management, managing risks of different types to a large number of assets.

Since 2010, RZD have implemented an integrated asset management system based on risk assessment. The URRAN system aims to support the decision making process for resources, risks and dependability at different asset lifecycle stages. URRAN includes three key elements – a distributed network of automated workstations gathering information on asset condition, methodological support based on the extension of international standards and a decision support system for railway management to provide recommendations on high risk assets or lines in need of investment or repair.

The system is driven by the ALARP principle (Risk as Low as Reasonably Practicable). Risks are tolerable if they cannot be reduced further without expenditure disproportionate to the potential benefit gained. Such a policy is in place to prevent investment in adaptation measures that are not economically viable.

URRAN incorporates a common industrial platform in compliance with ISO 55000:2014 including a system for comprehensive management of operational assets at all lifecycle stages and innovative technologies of supervision and control of technical safety.



Response to extreme weather events is assisted by RZD's Situational Centre, which collates information for all 16 regions of the Russian railway network to monitor the status of assets and the overall situation across the network. The centre is integrated with the emergency ministry and internal affairs, enhancing the capacity to react to emergency situations.

The primary functions of the Situational Centre are safety monitoring of infrastructure and rolling stock, forecasting incident risk and developing preventive measures, efficient response to and recovery from emergencies and reporting to senior management on traffic, operations, transport and fire safety at RZD facilities.

Experts based at the centre process weather information from weather and hydrological stations across the network to monitor and forecast conditions threatening traffic safety and rail operations. Preventative measures can be planned for individual railway facilities that can be enacted when hazardous conditions are observed.

Extreme weather response and adaptation is also supported by RZD Geoportal, an industrial system for the visualisation and analysis of geospatial information. This system includes radar satellite monitoring of infrastructure, for early detection of failures and processes that may lead to failure. Applications include monitoring of landslide stabilisation measures, identification of geodynamic processes using SAR data processing and fire risk assessment.

Adaptive Management

The concept of adaptive management is one in which adaptation takes place in phases, each phase designed to reduce overall risk to an acceptable level as the environment changes. However, instead of being planned to occur at fixed times, as in a traditional project management approach, these phases can be enacted when the overall risk reaches a pre-determined level. Each phase contributes to a larger plan and is designed so as not to prohibit future phases.

A prominent example of this approach is the TE2100 project protecting London from flooding. EA(2012)

Even where engineering solutions are necessary to improve resilience to weather and climate a variety of options may exist. For example:

- Where infrastructure is being newly built or renewed, the local design standards and specifications should reflect the best available information about the climate over the entire design life of that infrastructure. Where design standards specify values, consider whether these are appropriate in the light of the changing climate.
- Where existing infrastructure or services are at risk, more frequent inspection of these assets or routes may be an option. Consider using condition-monitoring equipment that can detect and signal failures to controllers to stop services safely. Such monitoring may be relatively inexpensive and can be coupled with increased maintenance as a cost-effective solution. The increased frequency and quality of data will also allow for better consideration of future adaptation actions.
- Where infrastructure cannot be viably protected from all failures resilience may take the form of pre-prepared repair plans and materials, for example fast-response teams on stand-by. Hazards forecasting and operational planning for transition to reduced

operations or even controlled shut-down may facilitate such plans, linking engineering and operational aspects.

The role of design standards and specifications

Engineers and designers routinely refer to design standards and these can be international (such as those produced by ISO), national or railway company specific. Reviews of design standards are one aspect of the emerging ISO14090 (appendix 6.6) on climate adaptation and an important way in which adaptation can be codified within the standards process.

National and international standards organisations typically have regular consultations on where new knowledge needs to be incorporated into standards documents. It is important that private and company standards and specifications are also reviewed on a regular basis and updated as information changes. One approach to avoid this becoming burdensome is to refer from design standards to other, more widely available and frequently updated information. Particularly in the case of climate change predictions it may be more effective to reference national information sources rather than include specific data that can rapidly become dated.

Even where wholesale protection cannot be justified it may be worthwhile to consider selective modifications. For example, in the US after Storm Sandy and in the UK at some critical locations, signalling and other electrical equipment has been raised to avoid flood water damage. Although this does not provide protection for other track assets or even against the most extreme flooding, it does enable more rapid repairs to be carried out after moderate, more frequent, events. Obviously, these types of engineering solutions are also fundamental to good asset management and again illustrate the close relationship to climate change adaptation of infrastructure systems.

Any assessment of the future will inevitably have to deal with uncertainty from many sources. In considering climate change there is often a focus on the uncertainty of climate hazard projections themselves, however quantitatively this is a relatively small uncertainty compared to that associated with future vulnerability and consequences of disruption in the railway business.

One approach to dealing with uncertainty is adaptive management which sets a strategy of staged option implementations over time. Each such option should permit flexibility for future options, avoiding actions which may compromise the ability to act effectively in future. For example, engineering solutions that require wholesale removal in future or are expensive to maintain, are thus unsustainable or block future adaptation. Adaptive management options are thus phased, and each phase is triggered when risks meet well-defined thresholds, assessed by maintenance inspections, condition monitoring and regular risk reassessment.

As mentioned previously the Adaptation Strategy may identify a variety of significant long-term impacts, which perhaps will develop slowly, and more immediate concerns about recent weather impacts. It is important to balance these and one method of doing so is to use cost-benefit (or benefit-cost) analysis (CBA), an economic tool that discounts the future benefits of investment over time.

CBA is a powerful tool that has many advantages. However, in the development of adaptation decisions it is important to realise its potential shortcomings. **The benefits of adaptation are improved resilience and a reduction in losses from future potentially disruptive events**. However, the likelihood that these benefits are at an unknown time in the future and of uncertain magnitude can make them appear unjustified if analysed alone by CBA because of the discounting of future benefits compared to current costs. In addition, CBA is a purely economic analysis which ignores the non-financial benefits, for example organisational reputation and impact to the wider community, of having a more resilient railway.

To address such concerns another approach that has been used is multi-criteria analysis (MCA). The WEATHER project (Doll et al 2012) considered MCA as a good option for adaptation option assessment. In this form of analysis options have an economic cost and benefit but also environmental and social impacts and benefits. Rather than a single cost-benefit ratio, the decision to proceed is based on reaching a variety of monetary and non-monetary criteria. These and other methods have been reviewed for adaptation through the ECONADAPT project (ECONADAPT, 2017) including case studies on large infrastructure development and benefits of adaptation for the wider economy. There is also a detailed discussion and examples of how both CBA and MCA can be applied to transport in the PIARC (2015) framework for road infrastructure.

This illustrates why adaptation planning and implementation should not be undertaken as a separate activity, but must be integrated into the basic activity of an organisation. Equally, economic analysis of options has a critical role to play in option assessment but should not be used as the only basis for adaptation planning and decision making. Rather the choice of options should all include adequate adaptation for the future climate they will experience, and meet the wider needs of the company objectives which will include safety and reputation. There should never be 'adaptation' and 'no-adaptation' options.

Cowley Bridge Junction case study

CBJ is an important railway junction in the South West of England that was part of the TRaCCA project as a case study for new investment appraisal techniques. Two options to alleviate flooding at the site, and a third to do nothing, were considered using two appraisal techniques:

- Standard Network Rail approach based purely on company revenue
- A revised WebTAG approach including the monetizable losses to the region served

The result of including Wider Economic Benefits (such as the additional time passengers and freight requires making the journey by another mode or route, severance costs in terms of wider business losses in the region and reputational damage to both the operators and the region) was found to be significant. Whereas considering the benefit:cost ratio using the Network Rail method had results of 0.8 and 1.6 for the two flood alleviation options, with payback times of 25 and 13 years respectively, including the wider economic benefits lead to BCRs of 3.9 and 7, with payback periods of as low as 3 years even with discount rates of 3.5% being applied. This is important to justify government expenditure on improvements.

A major scheme of works to improve the resilience of CJB is now underway.

Case Study: China – CRDC and CRRC

High Speed Rail infrastructure and rolling stock design

China Railway Design Corporation (CRDC) are an integrated survey and design consultant enterprise for the development of rail infrastructure in China. Most regions of northeast China frequently experience extreme cold conditions, including issues with ice and snow. In order to operate a safe and reliable HSR network in extreme cold regions, a variety of technical issues must be addressed such as frost heave deformation of embankments and construction quality control.

CRDC have developed a series of engineering design technologies to allow HSR to continue to operate in extreme cold regions. These measures are largely based on experience from the Harbin-Dalian and Harbin-Qiqihar HSR constructions. Adaptation solutions have been developed in three key areas:

Civil Works – Control and integrated monitoring technology systems for freeze-thaw embankments have been developed. Mono-block slab track, a filling layer and new materials for bridge bearing grouting have also been developed. The anti-freeze technology for tunnels has also been improved.

Electrical & Mechanical Systems – Key technologies of anti-icing, ice melting for OCS and snow melting for switches have been developed. Outdoor E&M equipment in severe cold regions can apply such technology to ensure continued functionality during winter extremes.

Operation and Safety Facilities – Ice melting equipment for EMUs has been developed. A range of systems have been developed or improved, including a fault detection system for EMU operation, cantilever condition monitoring system, disaster prevention and security monitoring systems, and an efficient operation and security system for high-speed EMUs.

Based upon the technology outlined above, currently eight HSR lines have been constructed in the severe cold conditions of northeast China at a total of 2659 track km, with a further 2572 track km under construction. For the Harbin-Dalian HSR line, operating since 2012, the experimental maximum speed reached 385km/h with an operational maximum speed of 300km/h, a world record for a HSR line in severe cold conditions. During the past five complete freeze-thaw cycles, continuous monitoring has shown the under-track foundation has remained in good condition. Equipment exposed to severe cold hazards such as blizzards have verified the reliability and safety principles of the adaptation technology.

Concentrating on rolling stock, CRRC ChangChun Railway Vehicles Co. Ltd. are a Chinese rolling stock manufacturer who have undertaken a research and development programme to improve EMU performance in extreme cold or sandstorm conditions. This work is based on the Harbin-Dalian and Lanzhou-Xinjiang HSR lines. Both lines experience extreme cold conditions, with Lanzhou-Xinjiang also being the first HSR line constructed in the sandstorm region in northwest China.

Operation of EMUs in such environments faces a series of technical challenges. These include the structural reliability of materials such as steel and rubber, vehicle dynamic performance including cross-wind stability and wheel-rail wear, aerodynamic performance, low temperature adaptability including condensation and sealing, altitude and wind adaptability including sand protection and clearing along with comfort issues such as air conditioning.

Research involving a comprehensive survey to identify key technical issues, simulations and experiments with EMU components, preparation of documentation and auxiliary measurements has lead to the development of three HSR EMU vehicles adapted to operate in extreme cold and sandstorm regions: CRH380BG, CRH5G and CRH2G.

3.2. Implementation of specific options

Once specific options have been generated, analysed and chosen to address the specific risks identified in the Adaptation Strategy, they can be implemented. The Rail Adapt framework does not consider in detail how adaptation actions are delivered as this will vary depending on the type of action and the type of organisation. However, these underpinning principles should always be considered as actions are implemented.

- Wherever design values are taken, these should embody the climate of the future reflecting the life span of the system
- Similarly, consideration should be given to the future economic and social environment and how the system may be used
- The implementation should reflect the best available information both from within the railway organisation and externally
- Implementation should integrate with the elements of existing asset management/investment plans

It is important that the Adaptation Implementation process reports progress, both internally feeding back into the next cycle of the Adaptation Strategy, and externally to any organisation which helped to set the initial objectives. This will demonstrate the value of holistic adaptation planning through specific achievements, and also increase the tacit knowledge and capacity of individuals and the organisation, which in turn embeds adaptation more effectively in business as usual.

Operational warnings for critical infrastructure

Railways in many countries have developed operational warning systems that allow weather forecasters to indicate where and when meteorological hazards will effect operations. One example of this is in Taiwan High Speed Rail who set thresholds for both wind and rain which are used by their weather service provider.

If rainfall is forecast to exceed 160mm over 24 hours (or 35mm in 1 hour) then additional monitoring of critical locations is undertaken. At 180mm / 24 hours (or 45 mm/hour) a reduction in operational speed is imposed and at 250 mm / 24 hours (or 50 mm/hour) services are suspended. Similar actions occur at wind speeds of 20 m/s (45mph/70km/h), 25 m/s (56mph/90km/h) and 30 m/s (67mph/110km/h).

These conditions typically occur on up to 5 days per year due to cyclones but significantly reduce the derailment safety risk. Climate change will potentially change the number of events.

It should be noted that even the best-prepared and flexible organisation will still encounter disruptive and unforeseen events. The success of adaptation cannot be simply measured against a train timetable, but rather requires an appreciation of the value of knowing and working more closely to the achievable limit in the circumstances.

What will the future rail system look like?

There are many visions of the future. Some are driven by visions of changing technology, some by the vision of individual passenger and user experience and others by wider economic, social and environmental goals.

CAPACITY4RAIL (2017) aims at paving the way for the future railway system, delivering coherent, demonstrated, innovative and sustainable solutions for Track design; Freight; Operations and Advanced monitoring.

In the LivingRAIL (2015) vision, electrified rail's share of the European transport market will dominate both freight transport and passenger transport for long-distance as well as metropolitan regions. This contributes towards a high quality of life in a sustainable Europe.

The Arup (2014) Future of Rail 2050 takes a user's perspective and explores how rail travel might change for passengers and freight. This incorporates trends in automated transport, control systems and personalised information.

Adaptation option planning needs to consider what the future rail 'system' will involve and how it may be used for the lifetime of the asset or development being considered. The EU CIPTEC (2017) project is developing a toolbox around innovation in public transport for European cities although this does not explicitly include adaptation issues.

Case Study: USA – New Jersey Transit

NJ TRANSITGRID

NJ TRANSIT is New Jersey's public transportation corporation. Covering a service area of 5325 square miles, NJ TRANSIT is the nation's third largest provider of bus, rail and light rail transit, linking major points in New Jersey, New York and Philadelphia.

To provide a resilient energy supply for a targeted core segment of critical rail infrastructure, NJ TRANSIT will construct a first-of-its-kind electrical microgrid capable of supplying highly reliable power during storms or other times when the central power grid is compromised. NJ TRANSITGRID is a result of a partnership between NJ TRANSIT, the New Jersey Board of Public Utilities, the U.S. Department of Energy (DOE), and the Federal Transit Administration (FTA) funded as a public transportation resilience project in response to Sandy under the federal Emergency Relief Program. NJ TRANSITGRID comprises two projects:

NJ TRANSITGRID TRACTION POWER SYSTEM

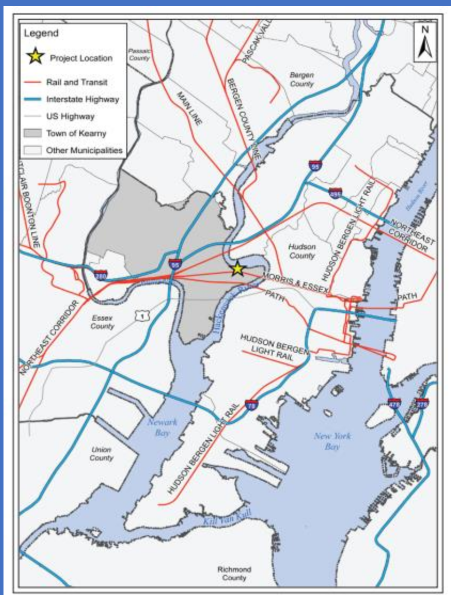
The NJ TRANSITGRID TRACTION POWER SYSTEM will consist of a central, natural gas power plant and transmission lines to traction power substations that electrify the tracks and operating controls on portions of the NJ TRANSIT and Amtrak systems. The proposed facility will operate 24/7 and be sized to handle limited operations on the Northeast Corridor between New York's Penn Station and NJ TRANSIT's Jersey Avenue Station in New Brunswick; the Morris & Essex line between Hoboken Terminal and Newark's Broad Street Station; the Hudson-Bergen Light Rail (HBLR) Transit System; and the signal system on a portion of the Main Line so that diesel trains can operate during a power outage.

NJ TRANSITGRID DISTRIBUTED GENERATION SOLUTIONS

NJ TRANSITGRID DISTRIBUTED GENERATION SOLUTIONS will incorporate distributed energy, renewable energy, and other technologies to provide resilient power to key NJ TRANSIT stations, maintenance facilities, bus garages, and other buildings in Northeastern New Jersey. NJ TRANSIT will purchase electric, non-revenue vehicles to maximise energy storage.

Location

The proposed location for the natural gas-fired electric power generating plant is in an industrial zone in Kearny, NJ, close to the two substations that serve the Morris & Essex Lines and the Northeast Corridor. Transmission lines will extend to substations in Kearny and Jersey City. Other elements of the project will be located at specific facilities serviced by those generation assets.



Project Location

NJ TRANSITGRID Energized Assets

Motivation and benefits

NJ TRANSIT's rail service is vulnerable to commercial grid power outages, which are occurring more frequently due to the nature of the existing central power distribution system and the intensity and frequency of severe weather events. In 2012, Storm Sandy caused major damage in New Jersey and New York and resulted in prolonged power outages to approximately 2.6 million utility customers. NJ TRANSIT's rail service operating between city centres in New York and New Jersey was severely affected. NJ TRANSITGRID is consistent with national and State priorities to modernize the electric grid. It will:

- Provide the electricity to enable safe, reliable, and resilient transportation
- Minimise disruptions to the regional workforce and economy
- Provide a cleaner and more efficient source of power compared to the commercial grid

4. Managing and supporting adaptation

Rail Adapt envisions "**a transport system in which the world's railways have acquired the flexibility to intelligently adjust to climate change, thereby providing their economies and societies with reliable and cost-efficient transportation services**".

To achieve this vision requires more than railway engineering, asset management or leadership. It requires development throughout the organisation to improve its ability to react more flexibly to changes. In other words, it requires the capacity to change internally in response to the changes that are occurring externally, such as to the circumstances in which it operates, including national policies, guidelines and local strategies.

4.1. Organisational capacity

To adapt a railway to changes in circumstance, such as climate change or other changes in drivers (travel patterns, population growth, urban development as examples) the railway organisation needs to be capable, having adequate capacity at its various management levels in order to respond to existing and emerging issues. This will entail a corporate ability to understand, consider, decide, plan, implement, monitor, evaluate, review and learn from these issues. Railways, being complex adaptive systems in themselves have an inherent ability to build capacity where it is needed. One challenge with climate change and adaptation is that, owing to its long-term nature, railways often need external drivers in order to consider adaptation measures in shorter-term planning cycles.

What is necessary to become more resilient against the effects of climate change?

"In my view, the key phrase is capacity-building. It's not just about money. Recently, I went to Cameroon, where they told me: 'When the British left the country in the 1960s, we had 49 meteorological stations. Now we have just three left at the big airports.'

So we need capacity-building, which enables the countries to absorb the money, the help and the expertise. In countries like those in sub-Saharan Africa this is absolutely key."

Hans Joachim Schellnhuber, Director of the Potsdam Institute for Climate Impact Research. MunichRe interview after COP21 (MunichRe, 2016).

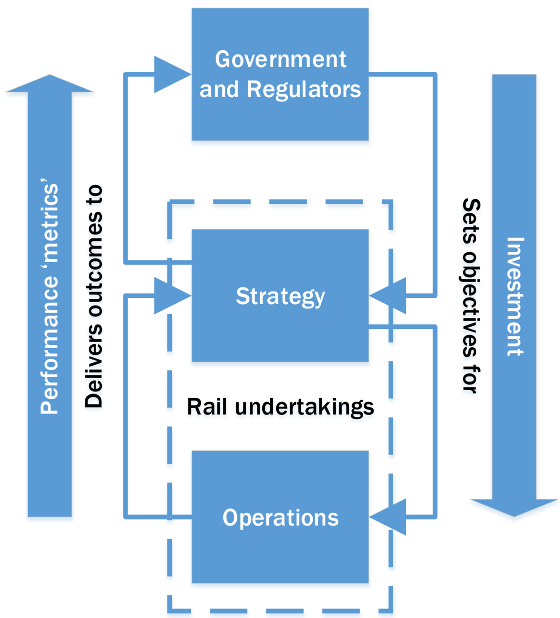
Today, plenty of drivers exist: United Nations declarations, the Paris Agreement, the Sustainable Development Goals, the EU and other multi-national adaptation strategies, National Adaptation Plans, and also rules governing long-term investments in, for example, upgrades. Railways need to understand the implications of these drivers at director level and to build the capacity to react, plan for and implement adaptation at policy levels, in strategic planning and in other functions such as asset management planning and implementation.

'Capacity' is not a novel concept. ISO55000 and its associated standards relate *capacity* to the capability to achieve the Asset Management organisation's objectives, whilst the IPCC (2014) glossary mentions 'adaptive capacity' as the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.

4.2. Assessing existing capacity

A first step towards building organisational capacity will be to understand existing capacity at various levels in the organisation. This can be achieved by undertaking a maturity assessment such as provided for in ISO55000 and supported by the associated UIC guidance (UIC, 2016).

The Institute of Asset Management has produced guidance (IAM 2016) which introduces the subject of asset management maturity. The self-assessment process defines maturity and presents a six-point scale ranging from Innocence to Excellence, for each of 39 criteria, and conformance assessment against ISO 55001. The UK Infrastructure Operators Adaptation Forum launched a pilot capacity assessment exercise with 5 members: Affinity Water, HS2, Network Rail, Northern Powergrid and Yorkshire Water. Each conducted an on-line company analysis, using Climate Capacity Diagnosis and Development software system (CaDD), and developed an Action Plan based on the results.



It is suggested the organisation assesses how adaptation requirements, actions, decisions etc. are understood by decision-making personnel (and processes) at Regulator, Strategic and Operational/ Local levels. The relevance of the hierarchy is that the parts of the organisation higher up give permission and set the parameters within which to those below make decisions and act. Regulators needs political direction, operations cannot perform without a Strategy, local actions do not happen without an operational framework that permits action.

For adaptation activities to be successful, each organisational level will therefore require an understanding, a blend of competence, skills and knowledge, of adaptation, its urgency and how to address its requirements. It is important to note that personnel need different levels of appreciation of the issues at stake, and all staff do not require the same degree of knowledge on adaptation. Top managers may consider country-wide or international issues over decades whilst local managers might be concerned with day-to-day matters on individual assets.

Interviews can be an effective way of determining existing capacity, targeting relevant key individuals at different levels, and drawing conclusions on organisational strengths and weaknesses, for example in policies, strategies, asset management plans, implementation plans, monitoring, evaluation, and reporting processes. Standards and competencies can also feature. Identified shortcomings will be the 'gaps' that can be addressed by help, forming an organisational capacity-building plan.

Measuring the performance of organisations

The Climate Capacity Diagnosis and Development software system (CaDD) developed by Climate Sense has been used by organisations such as Network Rail to generate metrics on organisational and stakeholder capacities across the business. The system helps an organisation to place itself against 6 response levels in each of 9 attributes – such as Awareness, Leadership, Learning and Managing Operations. It can then use this to set specific goals and actions to maintain strengths and address weaknesses in the organisation.

4.3. Building capacity

As railways are complex, adaptive systems, there is no prescriptive way that can be recommended for building capacity; the railway organisation itself will be able to gauge its strengths and weaknesses. Any gaps which are identified can form the basis of an organisational capacity improvement plan. This improvement plan would go into as much detail as is appropriate for personnel, policies, standards etc. Actions potentially could encompass:

- sourcing climate information;
- reviews of organisational objectives, policies;
- changing asset management strategies to permit adaptive design and maintenance measures;
- modifying technical standards, adopting appropriate design and maintenance parameters;
- (re) training of staff;
- arranging briefing sessions appropriate to organisational needs.

Railways would benefit in using 'systems-thinking' to scope capacity-building activities. Mapping interdependencies across internal activities and external organisations (e.g. supply chain) can help identify and prioritise activities that are crucial to capacity. This could lead to joint capacity-building exercises in conjunction with stakeholders - regulators, emergency response authorities, highway authorities, river authorities. Other national/sub-national institutions such as hydro-meteorological institutions, consultancies and climate service providers can feature.

Capacity can be affected by the ability of the railway's supply chain to deliver. Supplier contracts ought to be fit for purpose in terms of resilience. Legacy railway systems can find that existing supply contracts need significant review and modification, but for new construction, setting the right quality and technical standards would be easy by comparison.

Perhaps the greatest element of organisational capacity is embodied in staff. Retaining valuable experience and knowledge within the organisation as staff change is an important function of training and education. Consider how to engage with educational institutions who train the staff your organisation recruits and how the experience of staff can be passed on through training and procedural documentation.

4.4. Communicating adaptation

The need for good communication exists independently of climate change or adaptation plans. However, integrating good communication into adaptation planning is vital and has many benefits for a rail organisation.

In the development of National Adaptation Plans the voice of the rail industry needs to be effectively heard, addressing the need for issues of transport resilience and development to be central for policy goals to be achieved. Within the rail sector undertakings are encouraged to work together globally to develop common approaches and to work with other local stakeholders to develop risk-management partnerships. Within individual companies there is the need to develop understanding at all levels about the changes to standards, specifications and working practices that adaptation will bring, ensuring that it becomes "normal business" with lasting impact. Of course, customers are central to any railway business and therefore continued effective communication with them is also important.

Establishing effective ways of communicating with passengers and freight users before, during and after disruption events can help to minimise impacts as well as facilitate recovery work. The better understanding of stakeholder groups will also facilitate adaptation work where this may cause short term disruption, e.g. through renewals. Good communication also helps to ensure safety is maintained.

Passengers and freight users are likely to be primarily concerned about the availability of the services they use. Early warning of disruption can assist them in planning for alternative transport or deliveries through other means. Good communication across services, for example multi-modal planning, could even offer alternative services directly, although some studies suggest alternative services are not always popular with passengers. It is also important to consider whether the target audience is well covered by the means of communication used. For example, social media or other online platforms may cover younger passengers or those at home/work with good internet connections. However, older passengers or those currently travelling may not have immediate access to such information.

- The FUTURENET project found that during extreme rain and winter conditions rail is a preferred mode for long-distance passengers, which can be encouraged
- Social media provides an excellent platform for communication with passengers and potential passengers about the resilience of the network or multi-modal transport options during disruption

- Work with broadcasters and weather services can increase wider awareness and information available about weather and climate change impacts and the need for adaptation and resilience
- Short factsheets can be used for communicating with a wide range of stakeholders, for example those produced by the TRaCCA project for Summer, Winter and Flood conditions (Appendix 6.5)

Similarly, when seeking to implement adaptation plans the lack of support from senior managers and other stakeholders is often perceived as a key barrier. The development of a business case which communicates the rationale behind the proposal, particularly the importance of weather and climate on the performance of the network, is critical. The information developed in the climate change strategy, particularly the risks and consequences, can be used to raise awareness ahead of specific proposals and this will make approval more straightforward and timely.

The mechanisms and messages that need to be communicated will vary at each level and stage, however, common themes include:

- Company directors may routinely have summary safety data presented to them as they are legally responsible for safety policy. Developing similar weather resilience or asset vulnerability data may improve adaptation decision making
- Advising government and transport regulators in groups representing the wider society can be effective in emphasising the wider impact of rail investments
- Encouraging or forging links between government ministries of transport and environment to work together promoting and approving adaptation as a priority for national development
- Engaging with emerging national adaptation plans to shape future development and policy, ensuring that policy conflicts such as fuel cost and taxation differentials between modes are addressed.

The Institute of Environmental Management and Assessment (IEMA) have developed guidance for environmental and sustainability practitioners which gives key principles in building a business case (IEMA, 2013). These overlap with the steps within the Rail Adapt framework and include:

- Understanding the specifics of the business and context
- Engage widely and build awareness, seek partners
- Use existing decision-making processes
- Look for opportunities to 'add value' to existing projects
- Use recent and future weather impacts as an opportunity
- In addition to risks, consider opportunities and advantages that come with being more resilient and adaptive.

Communication with passengers, users and stakeholders

The LivingRail project (2015) developed a vision for rail transport in Europe in 2050 and the detailed steps that are required to achieve it. This included 62 complex measures covering 10 areas of activity: networks, rail reform, planning instruments, customer-oriented services, city planning, financing, mobility management, train stations, rolling stock and regulation. Working with the Pro-Rail Alliance (Allianz pro Schiene) a video was produced to support the communication of findings in a readily accessible form which can be viewed online.

This non-commercial alliance of 23 non-profit organisations and over 135 companies from every part of the railway sector work in collaboration, producing newsletters, press briefings and on projects such as LivingRail. The motivation of the alliance is the promotion and improvement of rail transport in Germany, particularly the role that rail can play in climate and environmental protection. However, the alliance is unique in that it is not purely an industry association, amongst its members are many civil society organisations, construction companies, banks, insurance companies and even road transport clubs.

It is funded partly by contributions from the rail industry as an investment in effective communication. This type of alliance is unique in Germany and is seen in many places as a "strategic alliance showpiece". In communicating and lobbying the diversity of the alliance enables creativity and a holistic view of transport and the role of railways.

5. Conclusions and Recommendations

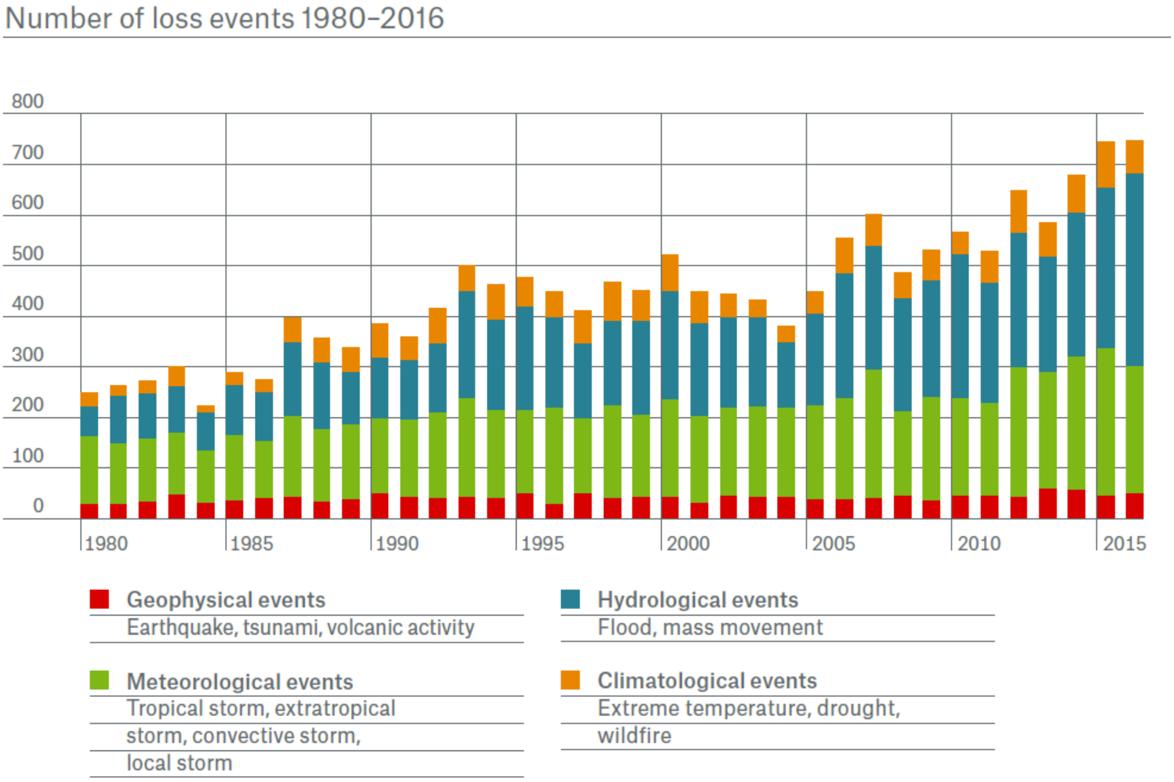
- The Rail Adapt vision is for "**a transport system in which the world's railways have acquired the flexibility to intelligently adjust to climate change, thereby providing their economies and societies with reliable and cost-efficient transportation services**".
- The Rail Adapt vision and framework foresee not a 'special project' or new undertaking for rail organisations but adaptation integrated with business as usual.
- This Rail Adapt framework helps railways to support government commitments such as the Paris agreement on climate change, the UN Sustainable Development Goals and National Adaptation Plans.
- In the development of National Adaptation Plans the voice of the rail industry needs to be effectively heard, addressing the need for issues of transport resilience and development to be central for policy goals to be achieved. Within the rail sector undertakings are encouraged to work together globally to develop common approaches and to work with other local stakeholders to develop risk-management partnerships.
- Most organisations will have existing risk management capabilities, which will already have experience of identifying and managing risks associated with safety, security and business continuity. Risk associated with climate change should be added and included within these processes if they are not already present.
- Adaptation must involve people from across the organisation each considering it from their perspective. Adaptation must also involve partnerships with stakeholders, suppliers, passenger and freight user groups working together. Organisations may also need to link up with experts in:
    - Transport Planning and engineering
    - Environmental science and engineering
    - Meteorology and climatology
    - Hydraulic and hydrological engineering
    - Geology and geotechnical engineering
- Adaptation is a normal function of business, bringing together elements which may currently be disparate or separated to improve business outcomes.
- There are a wide variety of options for improving resilience through adaptation in existing and new infrastructure, organisation and

operations. Assessing these in a structured framework will improve the effectiveness and value of adaptation.

- Adaptation options also include monitoring and gathering better data on which to base future decisions.
- Addressing risks early and in a structured manner may require no additional cost because adaptation measures can be factored into routine maintenance and renewal.
- If a growing population is exacerbating the consequences of disruption, then options to increase capacity with renewal alongside improved resilience may be appropriate and an opportunity.
- The benefits of adaptation are improved resilience and a reduction in losses from future potentially disruptive events.
- Adaptation requires leadership but there is the knowledge and tools to achieve significant benefits.

6. Appendices

6.1. Climate Change information signposting

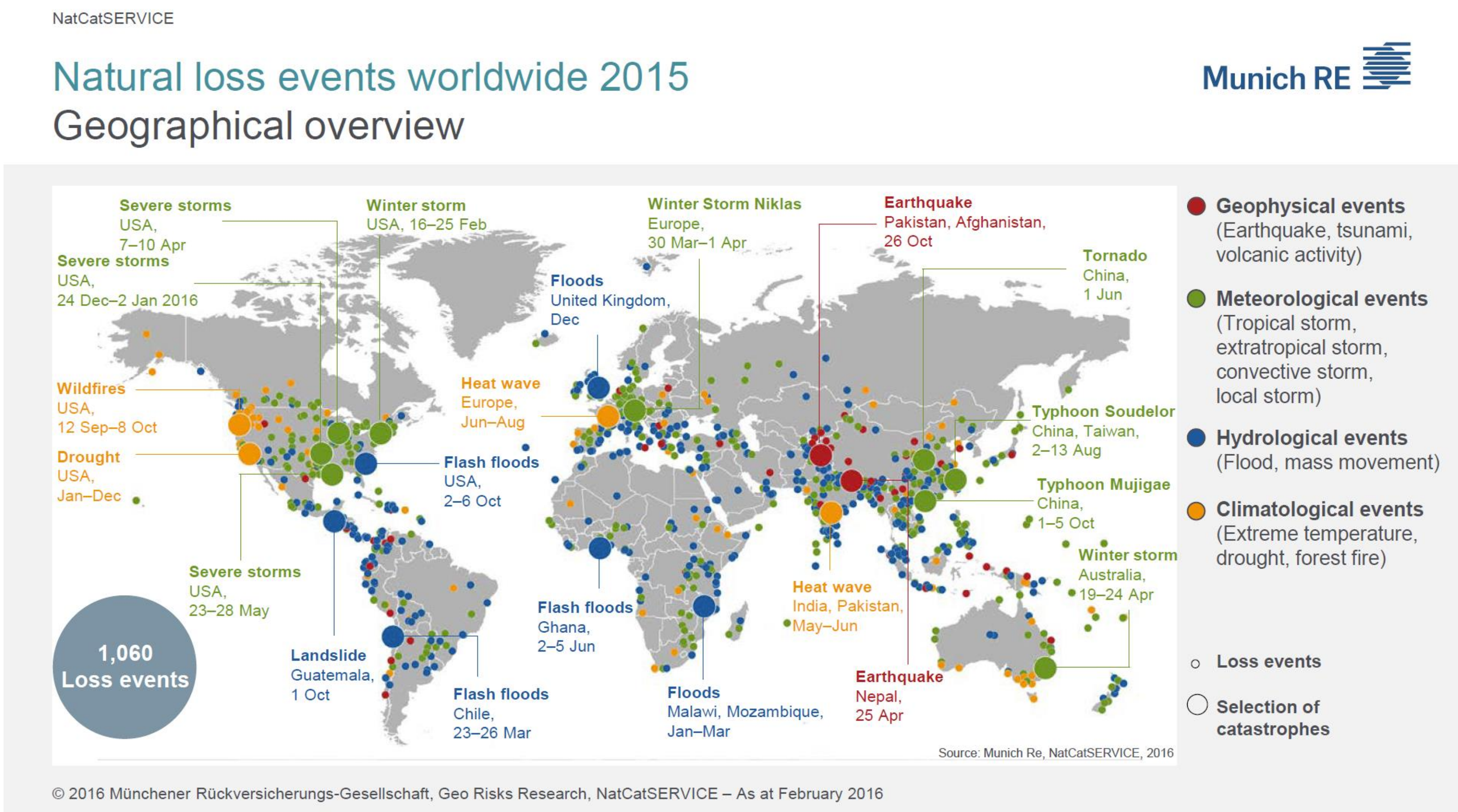


After Munich Re (2017)

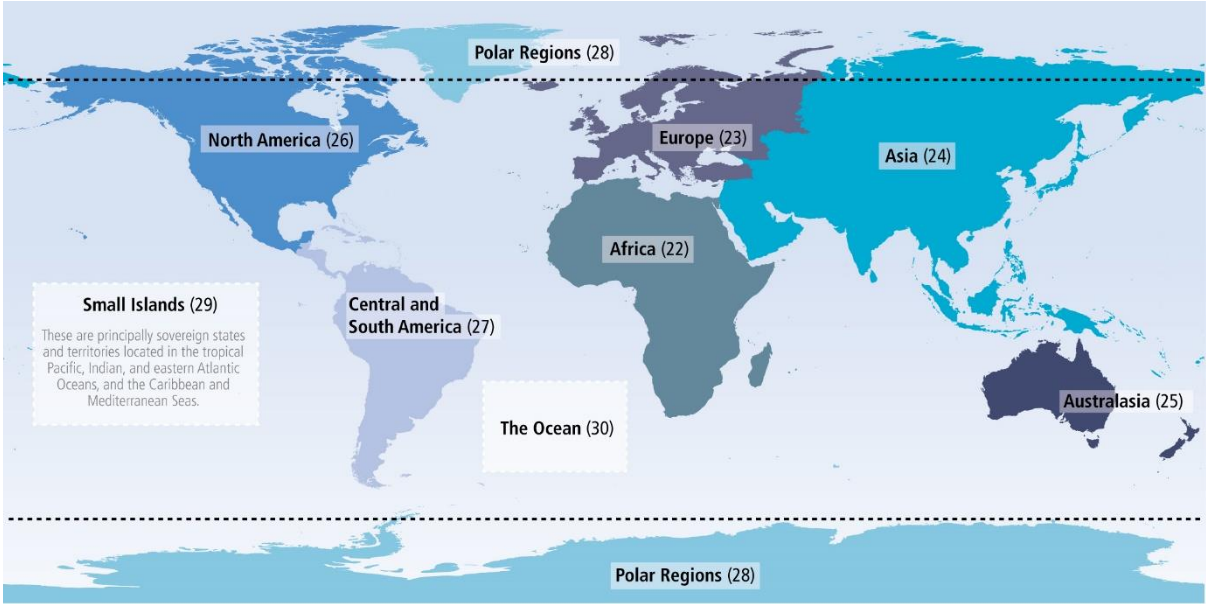
There has been a steady growth in disruption costs due to extreme events and other climate impacts and this is documented by insurance and reinsurance companies. Services such as the NatCat (Munich Re NatCat Service, 2017) and CatNet (Swiss Re CatNet Service, 2016) can provide detailed information about insured and uninsured losses.

These can be of value in developing an adaptation risk assessment and in communicating the reality of risks to a wider audience. For example, it is apparent that the increase in the number of loss events in recent years is being driven by meteorological (storms) and hydrological (flood, landslip) events (MunichRe, 2017). Such events are often those most of concern to railway undertakings. That this increase is also partially driven by the increase in populations living in vulnerable areas does not reduce the risk to transport systems as these are exactly the areas that new services will be expanding into and therefore of more, rather than less, concern.

This information can also be provided on a geographical (regional or national) basis and offer users bespoke data and analysis services.



After Munich Re (2016)



IPCC (2014) AR5 Adaptation Report – Part B, figure 21-1 showing chapter numbers for each region.

There are good sources of information and understanding about potential climate changes for all areas of the world. Many local meteorological services have produced models and assessments of likely future climate for their areas. These compliment major international studies carried out and complied as part of the IPCC process. The latest IPCC reports (the 5th assessment) now cover the underpinning climate science, adaptation (impacts and how they can be addressed) and mitigation (reducing GHG emissions). Within the IPCC adaptation report (IPCC, 2014) there is a section (part B) specifically on regional aspects which provide the best available information about likely climate changes to local areas and the impacts these are likely to have on different natural and human systems, such as transport. Regional climate change summaries are in chapters 22 (Africa), 23 (Europe), 24 (Asia), 25 (Australasia), 26 (North America) and 27 (Central and Southern America).

This report also contains illustrations of adaptation in context - chapter 24 (Asia) gives an example of how improving drainage in Mumbai could reduce extreme flood losses by 70%. It is also noted that in extreme events transport and power infrastructure can be disrupted across large areas. However, these failures are rarely due to a single cause, instead being linked to complex social, political and environmental factors, and therefore require multiple stakeholders to engage in developing an effective adaptation plan.

The IPCC have also produced a special report on management of risks from extreme events to support adaptation (IPCC, 2012). It presents an analysis of the changing likelihood of different types of extreme events for large regions of the globe (Chapter 3) and associated climate impacts on populations and eco-systems (Chapter 4). This comprehensive report also includes the integration of policy and financial elements into adaptation for extreme events as well as dealing with issues of global, national, regional and local scales in building capacity for risk management through adaptation (Chapters 5-7) and for sustainable development (Chapter 8).

For regions that do not have their own detailed information, or where existing information is dated, it may be useful to note that a new set of climate projections (UKCP18) will be published in 2018 by the UK government (UK Climate Projections, 2017). This will include global information for the first time, at a resolution of around 60km, for the full range of climate variables. This is likely to be an excellent source of useful information at a more detailed resolution than previously available. The initial launch is currently scheduled for March 2018 with full information being available in November 2018.

The EU HELIX project will also be offering High Resolution time-slices and regional downscaling for detailed regional impact assessment over Europe, Africa and Asia. These will be based on the results provided by a variety of models which contributed to the latest IPCC assessments as input to global scale impact assessments.

The Climate projections & observations tool (ClimGen, 2015) provides nationally based information for many countries at a monthly rather than annual resolution. The purpose of this web-based tool is to support studies that need to consider the spread in projections of future climate change produced by different climate models under different emissions scenarios. It does not provide probabilistic projections of climate change but may be useful for some types of studies, particularly when exploring the range of possible hazards and seasonality. Osbourne et al (2016) provides further information.

The Climate Impact Lab (2017) is a US based project, but with global data, led by the University of Chicago which seeks to help business leaders, policymakers, investors, and other stakeholders to address the climate questions they face:

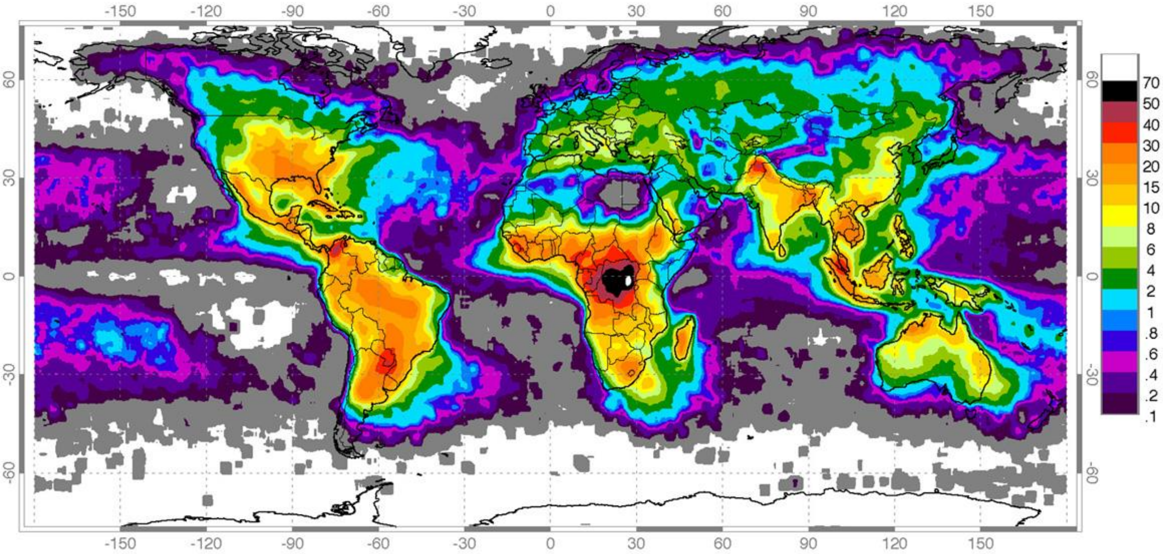
- What impact is climate change having on my supply chain, my investment or my local community today?
- How will this change going forward?
- How can that risk be mitigated by investing in adaptation?
- How much will it cost?

Climate Impact Lab aims to assist in answering these questions at the level of detail and with the level of rigor required for effective decision-making. It combines cutting edge climate science, statistical and mathematical research, data engineering, and advanced computing to produce evidence-based climate risk information at the local level. One example analysis has been published by Hsiang et al (2017).

There are also regional initiatives, such as the Climate Cloud (2014) digital library in New Zealand. Originally generated for land based businesses, the library now contains resources on the risks, impacts and adaptation solutions from climate change and adverse events more generally. The library contains physical copies and links to reports, fact sheets and video, sourced largely from New Zealand organisations.

In Europe the Copernicus Climate Change Service (2017) is a major project of the European Union's Earth Observation Programme. It consists of a complex set of systems which collect data from multiple sources: earth observation satellites and in situ sensors such as ground stations, airborne and sea borne sensors. Copernicus processes these data and provides users with information through a set of services that address six thematic areas: land, marine, atmosphere, climate change, emergency management and security. Copernicus is marketed as a Climate Change Service, essential to underpin climate change adaptation by providing climate and climate change information and knowledge by means of accessible, reliable, timely, and user oriented products to different sectors.

The occurrence of electrical storms is a specific hazard which is typically not included in detail in climate change predictions because the convective scale of such storms is typically small compared to the resolution of the global circulation models currently available. However, the likelihood of electrical storms is predicted to increase due to the increased thermal convective activity in the atmosphere as temperature and humidity rise. This is often associated with particular seasons. Current lightning hazard maps are available from a variety of sources both regionally and globally.

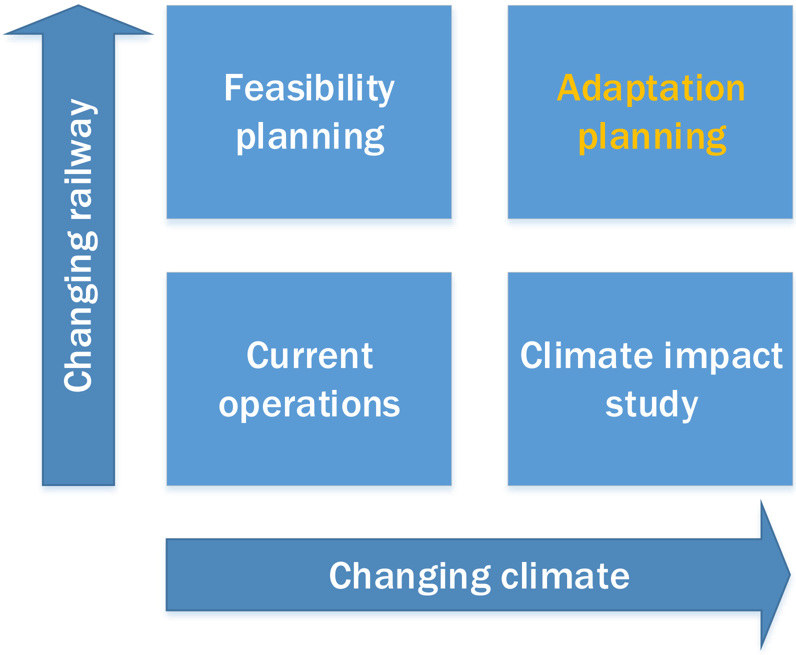


Lightning hazard map, strikes per square km per year (after Kao 2014)

Finally, another source of information is the Adaptation Clearinghouse (2017) which seeks to assist policymakers, resource managers, academics, and others who are working to help communities adapt to climate change. Although based in the US it is an independent non-partisan unit which focuses on climate change impacts that adversely affect people and the built environment including water, coastal, transportation, infrastructure and public health sectors. It provides access to many reports and resources through a single portal.

6.2. Risk Matrices

As mentioned in section 2.2.2, the assessment of which rail systems and sub-systems are vulnerable to specific climate and weather hazards is perhaps the most challenging element. Vulnerability will depend on specific location, micro-climate, asset type, age, condition and many other factors. However, broad qualitative assessments of primary vulnerabilities have been carried out by several projects.



These studies may have been specifically for adaptation planning purposes, but some were concerned with the development of new infrastructure (i.e. for feasibility planning) and others are based only on existing infrastructure as climate impact studies. Equally some have national or regional scope whereas others considered examples from around the world. Some are specific to the rail system whereas others consider transport or other sectors more widely. For example, the Energy sector is currently conducting a Natural Hazards review (ETI, 2017).

It is therefore important to consider carefully how transferrable these risks are to the context of your organisation and the specific context of the assets concerned. Also, be aware of the issues of dependency and interdependency (Section 2.2) and consider the potential for indirect impacts.

Lemaire et al (2012) conducted a review of the sensitivity of high speed and intercity operation with respect to various natural risks on an international basis. The review covered how the different risks could be mitigated at design stage either with actions on the infrastructure or on the rolling stock during operation, including the implementation of warning systems and alternative operating measures. The summary of results is reproduced on the following pages. Two specific studies (Gonzva & Gautier 2014, 2015) then looked in more detail at the risks associated with high winds and flooding.

NATURAL RISKS				
	Track	Power supply		Control
		Catenary	Substations	Signaling
High temperature	rail buckling	catenary dilatation		component he
Low temperature / Frost	rail broken	catenary freezing	Components freezing	
	switch malfunction			
	ballast stones thrown (ice coming away from trains)			
Snow / Avalanche	switch malfunction		components short-circuit	
	ballast stones thrown (snow coming away from trains)			
	track covered by snow			
	snowdrifts			
	destruction	destruction		
Change of humidity or high humidity			components short-circuit	
Strong wind		Short-circuits due to trees or branches which fall on the contact wire.		
Sand and dust	switch malfunction		sand/dust invasion into	
Heavy rain	Earthworks damages – Embankment collapses			
Flood, Tsunami	Destruction – Embankment collapses	destruction	destruction	destruction
			short-circui	
			no power supply from external providing	
Seashore corrosion	Embankment collapse	Rusty Components		
Fallen rocks	track destruction	catenary cut	substation damages	compo
Seismic event	infrastructure destruction	destruction		compo
		fire (short-circuit)	fire (short-circuit)	power supply loss
			no power supply from external providing	
Surrounding fire		Some components can be burned		
Salt injury	Rust	Rust		
		Reduction of electrical insulation performance		
Fallen leaves (for CR)	Slippery rails			
Thunderstorm	Embankment collapses - Destruction		Short-circuit No power supply from external providing	

POTENTIAL EVENTS			
Command and Signaling		Rolling stock	Operating
	Telecommunications		
ating		component heating	
		air-conditioning shutdown	
		pantograph failure	
		brake malfunction (hydraulic system)	
		components damages by thrown ballast stones	
		doors freezing	
(snow invasion)		snow packing	
		components damages by thrown ballast stones	
		components short-circuit (snow invasion)	
		brake malfunction (snow between disk and pad), derailment	
destruction		destruction	
		derailment	
(condensation)		components short-circuit (condensation)	
		overturning	
components		sand/dust invasion into components	
	destruction	destruction	Operating impossible
ts		short-circuits	
nents broken or cable cut		derailment / overturning	
nents broken or cable cut		derailment / overturning	
			operating impossible
		Rust	
		Reduction of electrical insulation performance	
		Locking of wheels	

19. SYNTHESIS

THE TREATMENT OF NATURAL RISK FOR HIGH SPEED AND CONVENTIONAL LINES

Natural risk	countries analysed	Exposure calculation methods	Thresholds of sensitivity / risk	Preventive measures at design/project le
Extreme temperatures / Frost	**Sweden, Japan, Norway,Germany, France**	Weather maps, statistics maps	Under -20°C, rail break risk = f (t, v). (Chalmers national suède) 45°C - thresholds depends on air temperature, rail temperature, air humidity, track lateral resistance and train breaks	References for new railways taken into account high temperature and local studi in case of extrem situations Design with ballastless track (France - prototype stage). Points and crossingsequipped with a point heating system.
Snow/ Avalanches	**Japan, Nordic countries China**	Local exposure maps	China: installation of snow depth meters in sections with maximum 10 years snow accumulation above 36 cm.	Snow falling predictions Japan: Infrastructures built where they ca be blocked by snow.
Change of humidity or high humidity	**France**		Variation of 60°C max	New ventilate systems. Air intakes at the higher part of the train. Sealing of boxes. Filterings of air conditionning.
Strong wind	**France , Germany, Italy, Spain, Japan, China**	Maps and local studies	CWC Matérial (european) France: Threshold 130 km/h to interrupt trafix (Mediterreanean LGV) China: installation of anemometers when wind speed exceed 15m/s	Risk studies,
Sand - dust				Filtering of water components. Strong sealing of components
Heavy rain /embankment collapse	**France, China, USA, Japan**	Level statistics and studies	France: Treshold for carry away of ballast China:installation of pluviometers in areas with greater than 200mm annual precipitation and for sections with high embankments, high moat and tunnel opening. Chinese wind alarm tresholds: -less than 15m/s trains can operate at normal speed. - less than 20m/s, trains are not allowed to exceed 200km/h. - less than 30m/s, trains are not allowed to exceed 120km/h - more than 30m/s trains are not allowed to enter in windy areas.	France: Risk analyses and modelisation identifiying exposed sectors
Flood/Tsunami	**Japan, France, USA, China**		embankment reinforcement	Alert, France: Risk analyses and modelisat identifiying exposed sectors USA : create inondation maps

evel	Detection/ forecast measures	Prevention of effects during operations	Mitigation by fixed measures	Curative measures	Calculation methods and reduction of risk
es	Temperature forecast for the planning of rail work and release of surveillance rounds during the hot season, Punctual/local surveillance of temperature. Measures in situ	Detection of broken rail. The contact line of the catenary is put on short circuit to heat it. Detection of rail buckling		Supply of water for passengers in case of air conditioning shut down.	Tools - based on modeling and a serie of measurements - exist for long run seasonal prediction and punctual prevision
n't	Japan: special cutting design, Warning systems for avalanches China: installation of snow depth meters.	Japan : sprinkler for wet snow, snowplough, hot water mat, hot water jets, air injection Nordic Countries: de-icing with propylene glycol, snowploughs, snow-thrower, rubber spoiler	Japan: deep parts along the track, Slaptrack “T-shape”, Ballast screens Nordic countries: anti-icing methods: polycarbonate mounted on an elastic layer, disc covers, snow brakes, heating system for magnetic rail brakes, measures providing collisions with animals...	Hot water jets to melt snow on rolling stocks and to help electrical heaters.	
	France/DEUFRAKO :Wheather-forecast, Re-routing of the train-traffic, Slowing down trains or interruption of cirulation China : installation of anemometers	Wind alerte système (France, Espagne, Japan) : automatical slow down of trains or stopped	Fences for viaduc or embankement (France)		
			Sand trap	Rerouting of circulations	
	China: installation of pluviometers, real time wind alarm	Detectors Radar surveillance permits detection of localized storms - collaboration with Meteo France. Weather alert. Japan: reinforcement of infrastructure China: real time wind alarm	China: installation of pluviometers	France : Construction of viaducts with hydraulic transparence Construction of submersible embankments USA: surge resources plan	Calculation method exist
tion	sensors	trafic interruption, USA : flood desk to reroute trafic	France: Detectors of flooded platform	Viaduc, submersible embankment.	

Seashore corrosion	**Japan**			Avoid building infrastructure near the seaside.
Fallen rock	**France**	Local exposure maps	Threshold: risk of derailment for blocks up to 10l.	Several protection systems
Seismic event	**Japan, France,Switzerland, Germany, Italy China**	Local exposure maps	Japan: - Threshold for a minor alarm: > 40mg et < 65mg : trains are automatically slow down to 170km/h - threshold for a major alarm : 65mg : l'interruption of train circulation	France: Regulation for high speed lines
Surrounding fire	**France**	high temperature Maps	depends on the congestion of vegetation along the track	large platforms
Salt Injury				no lines built near the seaside
Fallen leaves	**Netherlands, France**			Netherlands: Increase knowledge France: surveillance of wheels, size of tre campaign, installation of nets on the waysides, build up stock of wheels and ax Test of wheateher alert system and mode of falling leaves
Thunderstorm	**France, Japan**			

	Detection systems : géophones, radars, photogrammétrie	Detectors, detector	Screens, fences, nets		Calculation method exist
	Seismometers (Japan, France)		L-type rolling stock guide Rail over-turn prevention device Glued-insulated joint rail for seismic measures etc.		
		?			
	cartenary wasged regularly				
es cles. eling	Surveillance/washing	Netherlands: intelligent sanders Low Adhesion Warning Sytem, Improved WSP system,Train and instruct drivers, Autumn timetable, "Emergency" timetable, Autumn preparation in rolling stock workshops, Increase wheel lathe capacity, Communication plan France: brushing rail trolleys or “Kärcher trains”, reinforced train maintenance, Installation of anti-block braking system in trains.			
		Trains are stopped	Catenary’s posts all have lightning conductor to prevent power-cut.		

Gautier (2014) also summarised natural risks into those that are well known, and for which there are well developed control strategies, and those that are less well known and for which control is currently less effective.

	natural risk	risk treatment	
Well - known risk	Strong wind	Complete methodology available (F,D,Sp)...	☺
	Seismic events	Tresholds and several oprerational measures exist Construction antisismic?	😐
	Low temperature / snow	Several measures exist (Design and Curative measures, prevention plans?..)	😐
	Fallen rocks	Several measures exist (risk maps) Protection and detection systems	☺
Unwell - known risk	Flooding	Local alert systems, prediction possible, no thresholds	☹
	High temperature	Rail buckling risk monitoring available. Passenger discomfort when train stopped with no energy not covered	😐
	Fallen leaves	results NL study expected	?
	Surroundings fire	Operational preventive measures	😐

After Gautier (2014)

PIARC – the world road association, have also conducted an international review of potential climate change impacts (PIARC (2015) Appendix C). The list provided in that report is not meant to be comprehensive but can be considered as applicable to widespread infrastructure networks more generally. What follows is a summary which has been reinterpreted for the rail sector but is again not meant to be comprehensive.

Impacts associated with changing temperatures:

- Heat damage and deterioration of structures
- Thermal expansion of bridge joints
- Fire risk
- Overheating of electrical equipment
- Increased corrosion risks in coastal areas
- Health and safety for passengers and staff
- Changing frequency of fog and visibility issues
- Damage from early or repeated thawing
- Changes in pattern of usage, e.g. tourism patterns change
- Longer growing seasons for vegetation (alone or combined with storms and a greater risk of tree fall)

Impacts associated with prolonged and/or heavy precipitation and storms:

- Damage to tunnels, culverts, drainage and structures from flooding
- Increased runoff from adjacent land contributing to surface flooding
- Reduced safety as a result of standing water

- Reduced visibility
- Increased scouring of bridges and support structures
- Increased slope instability and landslips, debris, rock or mud flows
- Damage to earthworks and structures
- Overloading of drainage systems
- Inaccessible assets and sections of network
- Long-term deterioration of structures due to increase in soil moisture levels
- Health and safety risk to passengers and staff
- Pollution carried by surface runoff
- Bridge, sign and tall structure safety due to high winds
- Changes to groundwater pressure and subsidence

Impacts associated with sea level rise and heightened storm surge

- Damage to tunnels, bridges and structures due to more frequent coastal flooding and coastal erosion
- Damage to assets and structures from salt-water
- Damage to signs, bridges and tall structures
- Changes to groundwater pressure, level and salinity
- Reduced clearance under bridges
- Decreased lifetime of assets in coastal areas
- Health and safety of passengers and staff
- Permanent loss of coastal assets

Impacts associated with changes to snowfall, permafrost and ice coverage

- Possible reduced need for snow clearance
- Health and Safety for passengers and staff (whether more frequent events or less frequent due to loss of experience and familiarity)
- Changes in soil stability and ‘marginal’ days (around freezing)
- Increased ice/snow melt causing flooding
- Changing nature and location of avalanche risk
- Increased snow drifting due to winds
- Subsidence and weakening of structures due to thawing of permafrost
- Possible reduced ice load on structures
- Possible change in freeze-thaw action on deterioration of structures
- Landslips due to rapid thawing of ice/snow

Other potential impacts

- Reduced summer rainfall leading to reduced water quality
- Wind and sand storms, damage and reduced visibility
- Increased risk or extent of wildfires

- Areas cleared by wildfires then become more prone to landslides, flooding, subsidence or other impacts
- High winds in summer and debris being blown onto routes
- Operational constraints due to weather at exposed locations
- Increased frequency of electrical storms
- Increase in UV radiation and associated risk to staff and passengers

The World Association for Waterborne Transport Infrastructure (PIANC, 2012) have also collated a table of maritime adaptation responses which includes examples of adaptation measures that can be taken, with a particular emphasis on planning and contingencies.

Perhaps the most comprehensive review and analysis of current vulnerabilities specifically for the rail network comes from the TRaCCA project (2015b) but was confined in scope to Great Britain. The data were presented in two forms, one listing the impacts, potential controls and areas of further research required by meteorological variable (Appendix G1); the second listing the same information by railway system or sub-system (Appendix G2). The latter is reproduced here for information. For further information see the main Tomorrow's Railway and Climate Change Adaptation: Phase 1 Summary Report.

Tomorrow's Railway and Climate Change Adaptation: App G2: summary of information by system or subsystem

RESEARCH AND DEVELOPMENT

Written by: The Arup TRaCCA WP1 Consortium (Arup, CIRIA, JBA Consulting, the Met Office and the University of Birmingham) in collaboration with the RSSB Project Team (RSSB, John Dora Consulting Ltd and Network Rail), the TRaCCA Steering Group and expert stakeholders from the GB rail industry.

Published: June 2015

Appendix G2: summary of WP1 information by system or subsystem

The tables in Sections 6.1 – 6.7 provide a summary of all of the information contained in this report organised by **system or subsystem.**

The headings for each column are paraphrases of the headings of each of the previous sections of this report. Where a cell within the tables contains the text 'No data' or 'No guidance' or 'No procedures' we have sought to identify and distinguish the reasons for this being the case into three categories:

- **No data / guidance / procedures** = because data and/or guidance and/or procedures are not applicable to this climate variable or this asset
- **No data / guidance / procedures *** = because no specific data and/or guidance and/or procedures for the GB railway industry was found, but data and/or guidance and/or procedures from other industries and sectors may be relevant.
- **No data / guidance / procedures**** = because this is an area of current research or one which we suggest merits further work to obtain data and/or produce guidance and/or establish procedures

Whole system

	Weather / climate hazard	Weather impact on railways	Potential climate change impact on railways	Existing risk management	Recommended action
High Temperature	High temperature alerts	20 alerts & 1 adverse day per year. 0.25 extreme days per year in SE	High-T conditions projected to increase	Weather management process	Conduct threshold analysis of how frequently High-Ts are exceeded in future
Low Temperature	Low temperature alerts	No data **	Low-T conditions projected to decrease but not cease altogether	Weather management process	Conduct threshold analysis of how frequently Low-Ts will occur in future
High precipitation	Flooding	56,000 flooding delay minutes 2004-2010	Sign of change in heavy precipitation uncertain & varies by region / season; other factors also relevant besides precipitation	Weather management process	Conduct threshold analysis of how frequently rainfall amounts
Sea Level & Storm surges	Damage to railway from storm surge	£35m spent repairing Dawlish in 2014. Estimated £16m to operators.	Sea level projected to increase, greater increases in south than north. Storm surges uncertain	Weather management process	Collect data and analyse to scope size of impact
Sea Level & Storm surges	Flooding of railway from sea level rise	No data found	Sea level projected to increase, greater increases in south than north. Storm surges uncertain	Weather management process	Collect data and analyse to scope size of impact
High winds	High wind alerts	18 alerts & 4 adverse days per year. 0.3 extreme days per year in	Climate change impact on wind not clear	Weather management process	Better understanding of current wind impacts needed

People

	Weather / climate hazard	Weather impact on railways	Potential climate change impact on railways	Existing risk management	Recommended action
High Temperature	Heat Stress	Passengers force doors on trains. Possible heat stress effect on outdoor workers	High-T conditions projected to increase	Cooling down, drinking water	Collect and analyse data. Produce guidance for workers
Low Temperature	Slips trips and falls	No data **	Low-T conditions projected to decrease but not cease altogether	De-icing guidance	Analyse data to assess future risk
Low Temperature	Judgement errors working in cold	No data *	Low-T conditions projected to decrease but not cease altogether	Suitable PPE required	Produce guidance on suitable PPE & welfare

Rolling stock

	Weather / climate hazard	Weather impact on railways	Potential climate change impact on railways	Existing risk management	Recommended action
High Temperature	Reliability in hot water	Decreased reliability at high temperatures but not quantified	High-T conditions projected to increase	Design standards and seasonal preparedness guidance	Analyse reliability data Use threshold analysis to review design standards
Low Temperature	De-icing and snow clearance of rolling stock stabled outside	No data**	Low-T conditions projected to decrease but not cease altogether	Best practise guidance available	Collect data and analyse to assess impacts
Low Temperature	Icing of train horns, sliding doors, couplers	No data**	Low-T conditions projected to decrease but not cease altogether	Best practise guidance available	Collect data and analyse to assess impacts
Low Temperature	Traction motor failure due to snow ingress	No data**	Low-T conditions projected to decrease but not cease altogether	Occurred on Eurostar's and class 220/221 – now fixed	Include knowledge from previous problems in design standards
Low Temperature	Ice build ups detach at speed causing train damage	No data**	Low-T conditions projected to decrease but not cease altogether	Limit speed in snow and very low temperatures	Collect and analyse data to scope size of problem. Will determine if research needed
Sea Level & Storm surges	Traction motor failure due to salt water ingress	No data**	Sea level projected to increase, greater increases in south than north. Storm surges uncertain	Class 220/221 at Dawlish now fixed	Include knowledge from previous problems in design standards
High winds	Overturning risk	No data**	Climate change impact on wind not clear	Design standard, speed limits	Further data needed to scope problem

Operations

	Weather / climate hazard	Weather impact on railways	Potential climate change impact on railways	Existing risk management	Recommended action
Low temperature	Snow levels prevent train running	No data**	Low-T conditions projected to decrease but not cease altogether	Snow ploughs	Collect and analyse data to scope size of problem. Will determine if research needed.
	Roads prevent staff getting to work	No data**	Low-T conditions projected to decrease but not cease altogether	No guidance found*	Collect and analyse data to scope size of problem. Improve coordination with local authorities.
High precipitation	Train running limited when water reaches railhead	No data**	Sign of change in heavy precipitation uncertain & varies by region / season; other factors also relevant besides precipitation	Procedures in rule book	Collect and analyse data to scope size of problem. Will determine if research needed.
Low precipitation	Increased fire risk from steam specials	No data**	Uncertain and dependent on drought metric	Procedures in place	Data needed to scope problem, and determine if research needed
High winds	Obstructions on track	No data**	Climate change impact on wind not clear	Speed restrictions, service suspensions	Further data needed to scope problem
High winds	Increased risk of lineside fires	No data**	Not known	No procedures found	Further data needed to scope problem

CCS

	Weather / climate hazard	Weather impact on railways	Potential climate change impact on railways	Existing risk management	Recommended action
High Temperature	Overheating location cases	Data held by Network Rail	High-T conditions projected to increase	Shades, air conditioning, louvres	Use threshold analysis to allow assessment of future risk
Low Temperature	Snow & ice blocking or freezing points	No data **	Low-T conditions projected to decrease but not cease altogether	Point heaters, Design temp -25°C	Collect and analyse data to scope size of problem
High precipitation	Seals can fail with time causing problems	No data**	Sign of change in heavy precipitation uncertain & varies by region / season; other factors also relevant besides precipitation	No guidance found**	Collect and analyse data on impact
Low precipitation	Increased electronics failures at low humidity	No data**	Uncertain and dependent on drought metric	No guidance found**	Data needed to scope problem, and determine if research needed
Lightning and electrical storms	Damage to electronic equipment	No data found*	Not known	No guidance found*	Further data needed to scope problem

Energy

	Weather / climate hazard	Weather impact on railways	Potential climate change impact on railways	Existing risk management	Recommended action
High Temperature	Overhead line sag	Average 550 delay minutes per year	High-T conditions projected to increase but most vulnerable equipment replaced so impact not clear	Design limits, speed restrictions, seasonal adjustments	Use threshold analysis to allow assessment of future risk
Low Temperature	Ice formation on third rail	£6m per annum cost of anti icing trains and heaters	Low-T conditions projected to decrease but not cease altogether	Anti-icing trains. Third rail heaters	Collect and analyse data to scope size of problem
Low Temperature	Ice formation on overheads	No data**	Low-T conditions projected to decrease but not cease altogether	No guidance found**	Collect and analyse data to scope size of problem
High precipitation	Trains cannot run when flood water reaches third rail	No data**	Sign of change in heavy precipitation uncertain & varies by region / season; other factors also relevant besides precipitation	Procedures in rule book	Collect and analyse data to scope size of problem
Low precipitation	Movement of OHL due to soil shrinkage	No data**	Uncertain and dependent on drought metric	No guidance found**	Data needed to scope problem, and determine if research needed
High Winds	Trees branches blown onto OHLE	No data**	Climate change impact on wind not clear	Vegetation management	Further data needed to scope problem
High Winds	OHL blown out of alignment	No data**	Climate change impact on wind not clear	Design standard	Further data needed to scope problem
Lightning and electrical storms	Earthing and electrical conductivity issues for earthing arrays	No data found**	Not known	Managed through design*	Further data needed to scope problem
Lightning and electrical storms	Earthing & thermal conductivity issues for high voltage or dynamically loaded cables	No data found**	Not known	Managed through design*	Further data needed to scope problem

Infrastructure

	Weather / climate hazard	Weather impact on railways	Potential climate change impact on railways	Existing risk management	Recommended action
High Temperature	Track buckling	2 derailments since 2003, 26758 delay minutes per year, £9.2m per year	Costs projected to at least double by 2080	Rail stressing, speed restrictions, watchmen	Research required to gain a better understanding of stress around S&C.
High Temperature	Building cooling	No data*	Cooling need projected to increase due to climate change	No guidance or procedures found*	Gather and analyse data on railway building cooling
High Temperature	Swing bridge expansion	No data*	High-T conditions projected to increase	Local bridge management plans in place	Gather data on impacts
Low Temperature	Rail breaks	Average of 150 rail breaks per year	Low-T conditions projected to decrease but not cease altogether	Rail stressing regime	Review appropriate rail stressing regime as temperature changes
Low Temperature	Road grit causes track circuit failures	No data**	Low-T conditions projected to decrease but not cease altogether	No information, best practice to coordinate with local authorities	Collect and analyse data to scope size of problem. Improve coordination with local authorities
Low Temperature	Snow brings down trees	No data**	Low-T conditions projected to decrease but not cease altogether	Vegetation management	Collect and analyse data to scope size of problem
Low Temperature	Freeze thaw damage to concrete sleepers	No data**	Low-T conditions projected to decrease but not cease altogether	No information**	Collect and analyse data to scope size of problem
Low Temperature	Freeze thaw damage to earthworks	No data**	Low-T conditions projected to decrease but not cease altogether	Earthworks inspection regime	Collect and analyse data to scope size of problem
Low Temperature	Ice build up in tunnels	Derailment in 2010	Low-T conditions projected to decrease but not cease altogether	Capping tunnel shafts	Permanent tunnel capping designs required
Low Temperature	De-icing of carparks, pavements, platforms etc	No data**	Low-T conditions projected to decrease but not cease altogether	Guidance on best de-icers	Disseminate existing guidance

Infrastructure

	Weather / climate hazard	Weather impact on railways	Potential climate change impact on railways	Existing risk management	Recommended action
High precipitation	Increased risk of earthworks failure	11 derailments since 2005	Sign of change in heavy precipitation uncertain & varies by region / season; other factors also relevant besides precipitation	Network Rail adverse weather process	Improve understanding of trigger levels to work out future risk
High precipitation	Scour at bridges	13 failures since 1987	Sign of change in heavy precipitation uncertain & varies by region / season; other factors also relevant besides precipitation	Inspection regime	Assess if future water levels impact design and inspection requirements
High precipitation	Wet platforms & station concourses from footfall	No data**	Sign of change in heavy precipitation uncertain & varies by region / season; other factors also relevant besides precipitation	Mats, mopping. Local procedures	Collect and analyse data to scope size of problem
Low Precipitation	Increased risk of earthworks failure	No data**	Uncertain and dependent on drought metric	No guidance found**	Need to understand trigger levels to work out future risk
High winds	Trees or branches cause obstructions	No data**	Climate change impact on wind not clear	Vegetation management	Further data needed to scope problem
High winds	Increased autumn leaf fall	No data**	Climate change impact on vegetation not clear	Autumn management	Further data needed to scope problem
High winds	Third party objects blown onto track	No data**	Climate change impact on wind not clear	No procedures found**	Further data needed to scope problem
High winds	Work at height restricted (bridges / masts)	No data**	Climate change impact on wind not clear	Local procedures	Further data needed to scope problem
High winds	Damage failure of bridges	No data**	Climate change impact on wind not clear	Bridges closed above design wind speeds	Further data needed to scope problem

Infrastructure

	Weather / climate hazard	Weather impact on railways	Potential climate change impact on railways	Existing risk management	Recommended action
Lightning and electrical storms	Damage to lineside trees	No data found**	Not known	Vegetation management	Further data needed to scope problem
	Damage to buildings	No data found**	Not known	Managed through design*	Further data needed to scope problem

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6.3. Climate Adaptation project checklist

This section draws on the earlier work of Beckford (2008) considering the resilience of national infrastructure systems. It is also supported by information from the European Financing Institutions Working Group on Adaptation to Climate Change (EUFIWACC) available through the JASPERS Network (2017) and EFIWGACC (2016). OECD also maintain a portal for Adaptation to Climate Change (OECD, 2016) which includes discussions of policy approaches, financial support and evaluation.

6.3.1. Resilience Assessment

Very simply – 'we don't know what we don't know' – it is rarely the case that either the strengths nor the weaknesses of the current railway and related resilience are sufficiently well understood for strategic priorities to be determined. This is partly because railways are such vast and complex systems, partly because the information structures and asset management systems that support them are rarely either sufficiently comprehensive or fully up to date.

Mistakes will arise, and some things are subject to significant uncertainty. Clearly a full adaptation audit of railway and related infrastructure would be a costly exercise and difficult to justify in cost-benefit terms for either a government or a private owner or operator of that infrastructure. It is suggested therefore that such audits, or condition assessments, should be dealt with as an integral part of future planning and development. These should be informed by ongoing time based and condition based assessments as well as the history of 'break fix' activity. Break fix information has the potential to provide information not just about particular assets but, through aggregation techniques, to enable comprehension of the vulnerabilities of classes of assets and types of geographical location (e.g. flood risk, erosion risk, heat risk).

It may be appropriate for rail organisations to develop national standards for railway Infrastructure Resilience. This could usefully be measured against public measures of expected performance with vulnerabilities and risks identified, mitigated or managed., Adopting such an approach would make the resilience demands explicit and provide the basis for modified business planning and 'Return on Investment' calculations – especially if a 'triple bottom line' is to be used – economic, social and environmental.

Recognising interdependency with other systems, a railway infrastructure project will link to the water, telecoms, power supply, waste and transport systems but not make any contribution to them other than that which is required for connectivity. Effective adaptation of the railway would require that projects be designed to accommodate the extreme weather events projected in in any particular country or location.

Creation of a resilient railway infrastructure means that we must develop a mechanism of adaptation which renders it ultra-stable. Able to stabilise itself – it will be sufficiently (and deliberately) inter-connected with other parts of itself and the transport networks that even when one route to effective operation is disrupted there are alternative operable pathways.

A resilience assessment should be completed for every railway considering:

- The range of operating conditions it is expected the railway will be competent within;
- The systems on which the railway depends;
- The capability/capacity of each system to meet the specified need;
- The contribution to the capacity of connected systems from the project;
- Contribution verification;
- The business model;
- The overall resilience of this system.

6.3.2. Section One: The Performance Envelope

What are the maximum and minimum (where appropriate) of the following ranges under which the railway is expected to operate:

- Temperature:
- Humidity:
- Wind Speed:
- Wind Direction:
- Depth of standing water:
- Depth of snow:
- Maximum delay:

6.3.3. Section Two: Reliance on Connected Infrastructure

The purpose of this section is to make explicit:

- the extent to which this project will depend on the availability of existing services;
- to evaluate (quantitative and qualitative) the increase in interdependency and/or risk that would arise from its completion;
- to quantify the degree of reliance.

Q1: What are the systems on which this railway depends?

For each, specify the need, quantity, consumption, performance parameters.

Q2: What is the capability of each of those systems to meet that need?

For each, specify the current capacity available and the extent to which that capacity would be utilised.

Q3: What characteristics of your railway will impose new, or different, demand peaks or troughs on the existing systems? When?

Q4: What alternative / back up/ failure arrangements will be in place?

Q5: What are the principal infrastructure risks to this railway?

6.3.4. Section Three: Contribution to non-Railway Infrastructure Resilience

The purpose of this section is to make explicit:

- the ways in which this project will contribute to increasing resilience in the dependent services;
- to evaluate (quantitative and qualitative) the decrease in interdependency and/or risk that would arise from its completion;
- to quantify the extent of reduction in reliance and/or increase in resilience.

Q6: What other industries, populations or services will become dependent on this railway?

Q7: How will supply be guaranteed?

Q8: What will the failure arrangements be?

Q9: How will that contribution be verified?

Q10: How will it be funded?

Q11: How will other users be charged for their reliance on this system and he benefits they derive from it?

6.3.5. Section Four: Actions Necessary to Improve Resilience

The purpose of this section is to make explicit:

- the actions necessary as a result of this project;
- to specify and quantify the risk reduction;
- to state the costs of mitigation action.

Q12: What actions will be taken in respect of each element of affected infrastructure?

Q13: What specific risks will be mitigated and to what extent?

Q14: What costs over and above the standard projects costs will be incurred by the mitigation actions?

Q15: What future risk costs are obviated by that investment?

6.4. MOWE-IT rail guidelines (reproduced from MOWE-IT, 2014)

Guidebook for Enhancing Resilience of European Railway Transport in Extreme Weather Events

March 2014

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MANAGEMENT OF **WEATHER** EVENTS IN THE **TRANSPORT** SYSTEM

SEVENTH FRAMEWORK PROGRAMME

The MOWE-IT project: The goal of the MOWE-IT project is to identify existing best practices and to develop methodologies to assist transport operators, authorities and transport system users to mitigate the impact of natural disasters and extreme weather phenomena on transport system performance. The project is funded by the European Commission's 7th RTD framework programme between October 2012 and September 2014. MOWE-IT is co-ordinated by the Technical Research Centre Finland (VTT) and involves 12 European research institutes and companies. For more details please consult our website www.mowe-it.eu.

This document contains guidelines and recommendations for the improvement of resilience of rail operations in extreme weather conditions developed by the project team and reviewed by rail sector experts at the MOWE-IT rail workshop. Following an extensive review of previous projects on the impact of weather on rail operations including EWENT (www.ewent.vtt.fi) and WEATHER (www.weather-project.eu), case studies were identified in three broad weather categories; Heavy rain, wind and snow/winter conditions. Brief summaries of the case studies are given here (Section 1).

A number of recommendations and guidelines for the reduction of weather impacts on rail operations were synthesised from the experiences reported in the case studies. These are split into long-term planning and resilience building measures and actions which can be implemented before, during and after a given event. These include a range of actions including improving the resilience of physical infrastructure to specific weather conditions, learning from past events and dealing with affected passengers. Section 2 highlights recommendations that are specific to the three weather event types. Section 3 introduces broad recommendations that are applicable to most weather-related events.

Intended audience

This document addresses governments and the management and board of railway companies (infrastructure and transportation). It does not directly address working and operative staff of railways. The authors recognize that these individuals are doing a good job in case of extreme weather conditions and do their best on the basis of information and equipment they have in case of hazards. Looking at the recommendations in this guidebook three aspects have to be mentioned:

- Most of them are very well known by experienced people in the rail industry, especially operative staff on the track, the control centres and the workshops.
- Gaps, shortcomings and difficulties are often a result of bad preparation, lack of buffers, resources for preventive maintenance and the number of skilled staff among others. These deficiencies result from political and/or management decisions.
- Without skilled and motivated staff we still have in railway companies, impacts of hazards can become even worse, staff-balance short comings mentioned above and in the guidebook. Unfortunately the number and motivation of local working and operative staff is shrinking in most railway companies.

The recommendations and findings are results of the case studies and the experiences in extreme weather conditions the authors identified from desk research or having been involved is as railway passengers. They should be taken into account for strategic decisions and adopting the rail system for extreme weather events. Indeed, some of the guidelines and recommendations have already been established previously but have been forgotten, neglected or disestablished in the only economical design of railways.

Case studies

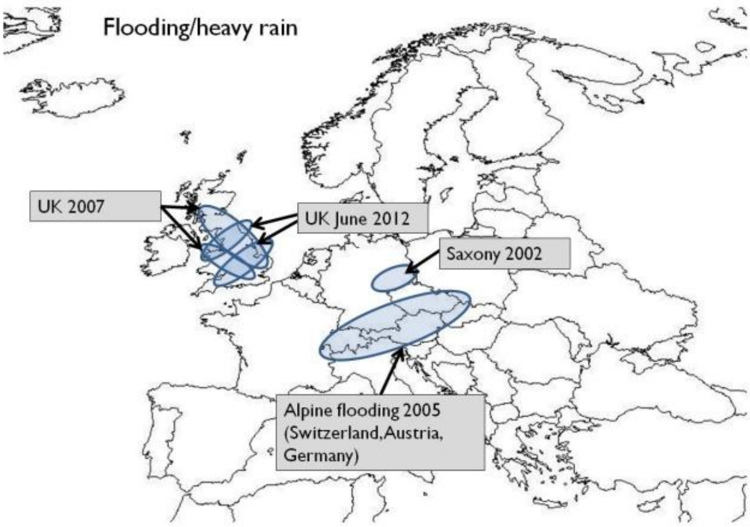
Heavy Rain

Saxony flooding 2002

This event saw widespread flooding across the region of Saxony. Dresden's central railway station flooded and 20% of the rail network across Saxony was destroyed. Damage was estimated at €0.8 billion.

Alpine flooding 2005

Flooding across a number of countries including Switzerland, Austria, Romania and Germany. Many railway services had to be suspended as lines were undermined or destroyed by landslides and bridges were washed away. Total damage was estimated to cost around €2.7 billion in Austria and CHF 3 billion in Switzerland.



UK summer flooding 2007

This event saw widespread flooding across the UK during July 2007 as a result of heavy rain. Many passengers were stranded and there was widespread disruption across the rail network. The economic costs are estimated to have been around £36 million.

Intense convective storms, June 2012

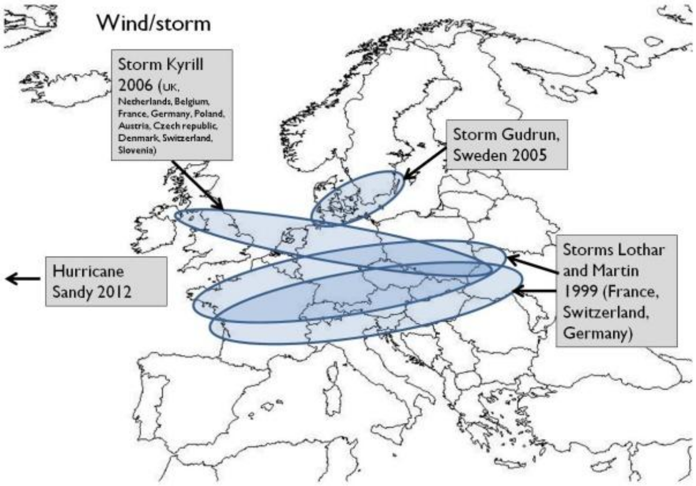
An intense convective storm of the 28th of June 2012 caused flash flooding and infrastructure damage, closing sections of both the East and West Coast Mainlines, temporarily severing rail transport between England and Scotland.

Heavy flooding, Central Europe, June 2013

In June 2013 heavy rainfall in Austria, Czech Republic and Germany (Saxony, Saxony-Anhalt, Bavaria) led to flooding of rivers in the affected regions, particularly true the Elbe. The team used the event to follow in real time the developments in passenger transport, especially the performance of newly introduced real time passenger information systems.

Wind/Storm

Storms Lothar and Martin, December 1999



On 26 December 1999 wave interference from the area of sea south of Ireland developed under a very strong frontal zone into a cyclone. This cyclone was called Lothar. Maximum wind velocities of around 250 km/h were measured in Germany. In the Swiss lowlands maximum gusts of wind were measured with a speed of 140 km/h. The second storm, which was called Martin, hit the Western coast of France one day later. The wind speeds of Martin were not as fast as the wind speeds of Lothar but damage arose from rain and subsequent flooding and also from heavy snow fall.

Windstorm Gudrun in Sweden, January 2005

The windstorm Gudrun hit Sweden's west coast on January 8th having been intensified to hurricane levels - winds of 31 metres per second were noted. Southern and western Sweden suffered the most from the storm.

Winter storm Kyrill over Western Europe, January 2007

Winter storm Kyrill hit the United Kingdom, the Netherlands, Belgium, France, Germany, Poland and in minor intensity Austria, the Czech Republic, Denmark, Switzerland and Slovenia over the 18th and 19th of January 2007. The overall losses were estimated at EUR 7.7 billion. Because of the heavy wind velocities up to 212 km/h in Poland large sections of forests were heavily affected and hundreds of thousands of households suffered power cuts.

Hurricane Sandy in North America, October 2012

The storm developed in the Caribbean Sea and then travelled northwards, developed into a hurricane over the Atlantic Ocean and then moved in a westerly direction towards the United States and southern parts of Canada. Winds up to 130 km/h were measured during this event in some areas.

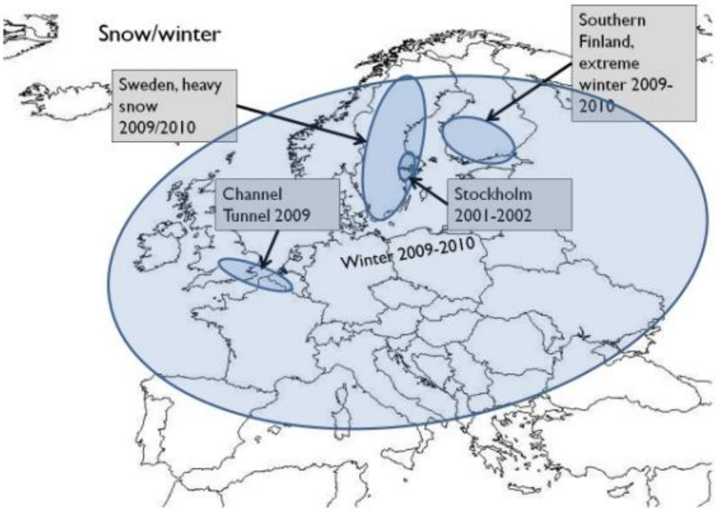
Snow/winter conditions

Heavy winter conditions in Stockholm 2001–2002

The weather conditions at the turn of the year 2001/2002 were exceptional in the Stockholm metropolitan area. According to the Swedish Meteorological and Hydrological Institute similar weather conditions occur about once every 15 years. Depending on the area the snow depth increased by 66-109 cm. Temperature stayed below zero during the whole period between December 19th and January 3rd and light powdery snow caused many problems.

Exceptionally hard winter conditions in Sweden 2009–2010

The winter of 2009–2010 was exceptionally cold in Sweden as well as in the other Nordic countries. The average temperature in southern Sweden was six degrees lower than the average of the previous 30–40 years. The average snowfall was not exceptionally high but due to the coldness the snow did not melt away.



Impact on winter conditions on Eurostar services, December 2009

Heavy snowfall in the Calais area on the evening of December 18th caused the closure of the Eurotunnel which lasted for four days. During the first evening of the heavy snowfall five trains failed inside the tunnel. This event caused direct disruption to the traffic between the cities of London, Paris and Brussels.

Exceptionally hard winter in Southern Finland, 2009–2010

The winter of 2009–2010 was exceptionally hard in Southern Finland. The continuous period of freezing weather began on December 30th and lasted for 60 days. Because of low temperatures and light powdery snow the ground frost lasted until June in many parts of the country.

Winter 2009–2010 in Europe

All parts of Europe were affected by the bad weather conditions during the winter of 2009–2010. The first incidents began in mid-December, but impacts of this extraordinarily strong winter (heavy snowfalls and very cold temperatures) occurred until April in some locations.

Weather-specific guidelines and recommendations

Heavy Rain

Before - Preparations for a heavy rain event tend to vary by location. In Saxony, few preparations were made ahead of the 2002 event, and as a result there were few strategies in place to deal with the effects of rainfall as the event went on. However, in New York for example the effects of Hurricane Sandy were pre-empted and as a result, the appropriate measures were put in place to minimise the damage caused to the rail network. Although the subway system was flooded, all traffic was interrupted before the storm and trains remained in depots for the duration meaning that no wagons were damaged and no injuries were incurred on the subway system.

A key determining factor in the level of preparedness appears to be the history of past experience of relevant conditions. For example, it was observed during the Alpine flooding of 2005 that Southern Bavaria was more prepared than other regions because of prior experience with the Whitsun flooding incidents of 1999. This included technical measures put in place for flood protection in the intervening period.

(Long-term preparation)

- Have flood response plans in place - prioritise use of limited resources during flood events
- Use improved flood prediction models incorporating better weather forecasts and much more detailed information on topography, infrastructure, geology and hydrology
- Enhance flood resilience of infrastructure where necessary or provide movable flooding walls. Work together with local authorities to have general local flood defence. Use inflatable dams)
- Improve and maintain drainage network along the rail network
- Clean drainage especially after autumn (in Essen there was flooding on the roads in November 2010 after some days normal rain due to clogged drainage by leaves)
- Incorporate climate change projections into the design of drainage to cope with predicted future flooding frequency and magnitude
- Consider infrastructure interdependencies. This especially applies to ensuring energy supply
- Explore relocation of important infrastructure to higher elevations and areas of lower flood risk
- Develop tailored plans for flash flooding and seasonal flooding

(Immediately before event)

- Flood warnings should be given in plenty of time
- Monitor drainage and solve problems quickly
- Deploy trouble shooting teams (drainage, bank repair teams)
- Install flood protection walls or inflatable walls
- Prepare water pumps for affected areas
- Interrupt operations before events occur

During- A number of responses to heavy rain and flooding are implemented during an event, often the response implemented depends on the nature and extent of flooding, as well as the measures which may or may not have been put in place prior to the rainfall. As would be expected, a common response is to remove any accumulating debris from tracks to enable trains to run once flood water across the track has subsided.

Where there is little preparation for a wide scale event, such as the floods in Saxony in 2002, more extreme responses are needed, particularly where an emergency is declared. The German Army provided 40 000 soldiers to assist following the floods - these were soldiers who had previous experience of dealing with the effects of adverse weather phenomena and could therefore help immediately. The use of inflatable dams to contain flood water is a new response being used by Network Rail. It was used for the first time in south west England in December 2012 to contain flooding at Cowley Bridge near Tiverton. The dams were successful in holding back water and preventing even more damage to the railway tracks following extensive damage to both tracks and the ballast beneath which had been washed away by floodwater.

When travellers' journeys are disrupted due to closure of railway lines during heavy rain events, alternative transport has to be found for passengers, be it replacement bus services or taxis. Of course, where there is also disruption on the road network then it is not possible to arrange alternative transport and passengers may be stranded as a result.

- Quick responses are essential to limit further damage – having flood response plans in place helps to facilitate this
- Reduce speed limits or stop trains in flooded areas where appropriate
- Clear tracks of any accumulated debris
- Personnel – having extra personnel on standby to help with additional duties during a flood event or to replace crews displaced by delayed/cancelled trains

After - Following heavy rainfall events, practices are often implemented to ensure that infrastructure is able to withstand a similar event in future. Infrastructure is often repaired to the same specification as before the event or modified to meet a higher specification. Track drainage is often surveyed following a flooding event to ensure there are no blockages which may impede drainage during future rainfall events. Where lines have to be reconstructed, priority tends to be given to long-distance railways first and then to local networks with repairs to stations and remaining infrastructure being of the lowest priority.

Repair work can take months and even years. For example, following the Alpine flooding in 2005, access to Engelberg was only restored once a new railway bridge had been built 5 months after the initial flooding occurred. A common response following a heavy rainfall event is to carry out further asset assessment. This identifies any damage to assets, repairs which need to be carried out and also where improvements may be needed to ensure that the infrastructure can withstand any future heavy rain events. Europe wide, there are a number of responses to flooding events which not only allow the network to begin operating again following a flooding event but also seek to reduce the risk of flooding during future events.

- Where repairs and reconstruction are carried out, damaged infrastructure should be upgraded to improve resilience to future flood events.
- Survey track drainage - identify and remove any blockages which may impede drainage in future.
- Implement flood control measures to protect tracks.
- Reinforce embankments which are particularly susceptible to landslides (construction of hillside fixing)
- Consider line relocations where tracks are particularly susceptible to flooding
- Construction of further sub surface drains in areas where flooding is a persistent problem.

Wind / Storm

Before – Prior to such events collaboration should be made with weather services in order to assess the weather situation and to initiate the proper operations beforehand. This is confirmed by the fact that the storm Kyrill was predicted a few days in advance. This led to the result that citizens prepared by using trains beforehand or by cancelling their travel plans. This was a good measure to prevent further disruption. Since predictions for extreme weather events like Kyrill are very important, the Austrian Federal Railways implemented a meteorological information and warning system. The requirements for such a system differ from existing official and private forecasts and meteorological information systems. In Sweden severe weather scenarios were already rehearsed beforehand so that the crisis management activities could be realised effectively. In Germany on the other hand there were only a few actions of management beforehand and during Kyrill. In most of the cases the affected companies were waiting until the storm set in and reacted during the event. Some literature indicates that during previous events the clearance of the tracks of hazardous trees and shrubbery was wider and thus more effective. The reason for the wider clearance was the higher risk of fire coming from steam engines. This reduced timber fall on rail tracks and catenary. Either way, it is important to keep the areas along the tracks clear from hazardous vegetation.

(Long-term preparation)

- Have wind response strategy in place - resources should be put in place before the events occur
- Use improved wind prediction models - wind warnings should be given as soon as possible
- Keep the areas close to tracks clear of vegetation and dangerous objects that may be blown around
- Improve the resilience of catenary masts, the tracks and station buildings
- Strategies for cutting departures and reducing passenger capacity should be put in place (special timetables, rerouting models)
- Train personnel (and subcontractors) to understand the specifics of clean-up and repair-works after heavy wind-events (during the clean-up works following the windstorm Kyrill there were several fatalities)
- Design a risk-based approach for speed restrictions and line closures

(Immediately before event)

- Interrupt operations before events occur and be prepared for this interruption
- Check the affected areas close to tracks and keep them clear of vegetation and dangerous objects that may be blown around
- Advance preparations for dealing with predicted impacts of wind event should be discussed (identification of persons/groups to coordinate the work, identification of critical locations, deployment of subcontractors, ensure the availability necessary resources like cranes, chain saws etc.)
- Deploy diesel engines in the areas likely to be most affected in the case of disruption to electrical equipment

During- One of the strategies used during storm Kyrill was the imposition of speed reductions to 160 km/h for long-distance trains and to 140 km/h for short-distance trains. Furthermore there were several railway sections closed due to timber fall and damaged catenaries. Later on nearly all railway traffic was cancelled. The decision was made after an intercity train was struck by an uprooted tree. Only a few corridors of the Deutsche Bahn-network were served. These decisions were all individual. Additionally some private companies still operated. In the Netherlands there also was a complete halt to operations at 20:00.

Immediately after storm Gudrun had reached Sweden in 2005, regional special crisis management and executive groups were activated both in the south and west. These groups consisted of chiefs responsible for different sectors (material service, production, information) at the Swedish Rail Administration. This type of group could provide the required speed and proactive response in decision-making. The most important task for groups was to create an operating strategy and operating plan. Furthermore, groups took care of communications, creating a general view of the event as well as assigning personnel and resources. They also determined priorities for measurements in the railway network in cooperation with other operational actors.

In addition to regional crisis management and executive groups, a national leading group was set up at the head office of the Swedish Rail Administration. The national leading group decided that during the crisis, freight traffic was prioritised at the expense of passenger traffic. In general, in order to get the rail traffic to operate properly again, large repair works were implemented. All workers were primed for their duties in special conditions in order to avoid accidents. Due to power and communications disruption, some railway sections and grade crossings were guarded by special road guards. Furthermore, diesel trains were used so that the most important goods could be delivered. On some railway sections freight traffic was operated on special terms during the traffic cancellations. Because organisations had practised crisis management in advance, they could manage the event relatively well. In addition, persons belonging to crisis management and leading groups were used to working together and it didn't take long to activate the operation of groups. Some additional resources were supplied even before the storm.

In some cases it was hard to put compensatory power stations and generators into use because it was not properly noted where these stations and generators were located. Some of the actions took too much time due to safety regulations because some of works are only allowed to be executed while there is a connection to the control centre. Because of the lack of power supply and thus communication connections were often discontinued so the repair works could not be executed. This has to be handled in a different way in future events.

In the future it should be possible to get a quick overview over the impacts of the event with the use of special software in order to issue instructions directly. Beforehand the process of "carrying together" all the damages took too much time. Additionally there were several differences concerning the quality of information. In these weather situations airplanes and helicopters should be used to get a quick overview of the impacts if it is safe to do so.

It is also necessary to establish certain criteria, when the use of a corridor should be cancelled or when certain measures should be taken into action beforehand. Additional criteria are needed when the cancellation should be revoked. It is also possible to ensure the transport of essential goods. During such an event the communication is very important and passenger information has to work. All participants should be trained beforehand and it is also possible to use the help of external coordinators.

- Ensure that the tracks are free of foreign obstacles
- Have additional personnel on standby to help with additional duties during a heavy wind event or to replace crews displaced by delayed/cancelled trains and to take care of passengers
- Reduce speed limits and cancel traffic where appropriate
- Use special timetables where traffic on lines needs to be reduced
- Keep trains inside the depot overnight

After – During the event it is necessary to get an overview of the damage. Following the overview of the extent of damage it has to be decided how the damage can be fixed and how much time these repair works require. Resources need to be classified and arranged. Additionally it might be necessary to install replacement schedules with differing departing times, delays and redirections and it also might be necessary to implement rail replacement services. It also is important to keep passengers informed about replacement schedules and about the schedules of rail-replacement services. Customers of rail freight also have to be informed about changes to schedules.

- Return to normal schedule as soon as possible
- Where repairs and reconstruction are carried out, damaged infrastructure should be upgraded to improve resilience to future wind events
- Regular clearing of vegetation along tracks
- Identification of critical locations
- Update of plans and strategies in light of lessons learned

Snow/winter conditions

Before - Based on the case studies the preparations for the heavy winter conditions tended to be ineffective in many ways. In Sweden (at the end of 2001) the railway organisations had raised their level of preparedness due to the received meteorological information but there was still not enough maintenance personnel, machines and equipment for snow and ice removal. In the Channel Tunnel the potential for condensation had been reduced by modifying the design and positioning of circuits and by ensuring a common bloc is warmer when entering the tunnel to reduce thermal shock. No other preparations were directly indicated in the case studies. In turn, it was mentioned in the Swedish case study (2001–2002) that preventative maintenance had been neglected during the previous years.

(Long-term preparation)

- Increased preventative maintenance (critical switches, pantographs and carbon strips, outdoor signalling equipment)
- Install snow covers of switches
- Install switch heaters
- Build of snow barriers
- Keep culverts and ditches open to keep the track areas and embankments dry to prevent damaged due to ground frost
- Train personnel and subcontractors to understand the specifics of winter operations
- Ensure the availability of spare parts, additional cables and other materials which are known to break in hard winter conditions
- Obtain snow and ice melting equipment and investigate of options to modify the rolling stock to prevent snow and ice accumulation on undercarriages
- Specify and test new infrastructure (especially switches) to resist winter conditions or avoid snow build-up.
- Focus winter-proofing/snow-proofing in key areas

(Immediately before event)

- Ensure that the track profile is free of foreign obstacles (no braches of bushes covered with snow hanging low and avoidance of ice formation at tunnel entrances)
- Increase defrosting capacity (increased depot space), and cover of the most important railway yards
- Deploy reaction teams and equipment (engines, rotary snow ploughs)
- Deliver spare parts, cables and engines to local critical areas
- Prepare rolling stock and infrastructure for snow and cold weather (e.g. heating, removal of ice and snow)

During - During the heavy winter conditions the focus was on snow removal to keep the tracks and switches operational (with and without machines), to keep the rolling stock in operational condition and to repair the damaged track areas (caused by ground frost) by supports. It had been identified both in Finland and in Sweden that the cooperation between the different operational actors did not work well enough. The actions were put in place too late and the snow removal took too long. It was also identified that the subcontractors' resources for snow removal were inadequate. Several problems in gathering and sharing information to passengers, between operators, and to the general population were also identified. The passengers were either helped to reach their station of origin or destination. In some cases this was done by buses when not enough trains were available in reserve. In Finland, special timetables with fewer trains were taken into use.

- Manual cleaning of switches (brushes, spades, blowers, excavators)
- Remove snow (snow blowing machines, snow blow trains, by hand)
- Keep trains inside the depot overnight or cover sensitive parts (couplings, pantographs, switches)
- Heating of trains through the night
- In areas using third rail electrical systems keep trains moving across track overnight to reduce ice build-up
- Resistive heating of OLE to reduce ice build-up
- Take measures to keep platforms free of snow and ice

After - Several recommendations that were identified to ensure better preparedness of railway organisations to upcoming heavy winter conditions. Following the Channel Tunnel event the recommendations were divided into three broad categories which were (i) increasing train reliability, (ii) establishment and regular updating of evacuation and response plans and (iii) improved communication and management of the situation.

Several recommendations that resulted from the other case studies fit into these same categories. In Finland it was emphasised that the cooperation between different actors needs to be improved and the management procedures need to be made systematic and documented. Therefore, the establishment of new working groups to improve the cooperation between the different actors participating in operative traffic management was recommended. The aim was to provide speed and proactiveness in decision-making. In Sweden it was recognised that the cooperation between traffic control centres was challenging since technical systems for controlling railway traffic varies in every traffic control centre and thus improvements are needed. It was also emphasised in Sweden that practical training should be organised so that every actor knows how to carry out the work in extreme situations.

There were also several recommendations concerning the need for additional resources (personnel, machines, equipment). The need for new glycol based snow and ice melting equipment and new switch-heating systems was identified (Finland and Sweden) with special attention paid to the most critical points in the railway network. More attention should also be put to preventative maintenance (maintenance processes will be made systematic and be documented) and on the availability of additional (competent) resources for the snow removal.

- Identification of critical locations
- Update plans and strategies in light of lessons learned
- Elimination of the worst bottle necks such as single-track sections

General recommendations and guidelines

Table 1: General recommendations and guidelines for managing the impacts of extreme weather events on rail transport

Area	Long-term preparation	Event management
Weather forecast	• Cooperate with weather forecast providers • Install local weather forecasting systems where needed • Establish meteorological thresholds and triggers for actions and refer to asset condition databases for local adjustments	• Use weather forecasting systems to determine areas likely to be most heavily impacted and deploy equipment, staff and prepare vehicles accordingly
Vehicles	• Assess vulnerabilities of vehicles to specific weather types observed during previous events • Adapt vehicles and enhance resilience	• Fit vehicles with extra equipment appropriate for weather (e.g. snow ploughs) • Heat/cool/clean/cover vehicles to ensure they are in operational condition • Check vehicles for weather-related issues (e.g. frozen couplings, bogies and doors)
Infrastructure	• Assess weather-related infrastructure problems identified during previous events • Maintain asset condition database and integrate with weather forecasts • Install redundancy and emergency capacity (pass-by trucks, switches, operation on opposite lane) • Keep areas close to tracks and catenaries free from hazardous objects and vegetation	• Check infrastructure for potential failures (e.g. blocked drainage, frozen switches, unsecured items) • Prepare infrastructure and carry out emergency maintenance (e.g. blocked drainage) • Deploy teams to observe vulnerable infrastructure (e.g. catenary, drainage, track) • Clear track of debris and other objects blocking the tracks or damaging the catenary
Equipment	• Plan which equipment is needed for local hazards (e.g. pumps, deicing machines, rotary snow ploughs, movable dams, cranes) • Check the availability of equipment and spare parts and plan storage • Provide logistic plans to deploy equipment and spare parts in case of hazards • Ensure the availability of diesel engines as replacement traction and provide contracts for use in emergencies	• Check the availability and functionality of equipment • Concentrate equipment and staff in the most affected areas • Deliver spare parts where needed • Deploy diesel engines and drivers in case of damage to electrical system
Operations	• Prepare emergency plans and general time tables (for rerouting, early turn around, reduced speeds) • Provide information for staff in case of emergency • Plan bus replacement strategies (stations, train the drivers, provide framework contracts). Replacement by bus should be well thought through as this has been a previous problem.	• Impose emergency speed restrictions • Establish special time tables if necessary • Interrupt or halt operations if necessary • Provide replacement services if needed
Information	• Prepare information systems for passengers and clients (online but also locally such as displaying emergency time	• Provide real-time information to passengers (e.g. internet, mobile data and traditional formats such as

Area	Long-term preparation	Event management
	tables) • Integration of different types of asset-monitoring databases • Raise awareness of adaptation to climate change • Establish greater regional and international exchange of good practice	flyers and bill boards) • Maintain communication with important institutions • Keep staff informed so updates can be relayed to passengers
Cooperation	• Plan and prepare emergencies with fire brigade and other emergency services • Develop hazard, vulnerability and risk mapping in cooperation with weather services • Foster cooperation among undertakings and institutions • Foster vertical and horizontal cooperation of public and private bodies	• Cooperate with local emergency services • Install common control and steering centres including rail and emergency services
Staff	• Train for trouble shooting and information provision in case of events and in abnormal operation • Build local trouble shooting teams with defined responsibilities • Practice emergency plans for severe weather (this should involve emergency repair work) • Organise joint training exercises with local emergency services • Identification of persons/groups to coordinate the work	• Prepare emergency teams • Deploy staff to locations of the event, depending on expertise needed • Deploy specialised staff for repair and for handling of special equipment
Legislation	• Prepare and agree with local or national governments priorities and minimum service standards which should operate as long as possible and to be reintroduced as soon as possible (freight or passenger, local or long distance, try to operate one train per hour (skip the other trains etc) • Make agreements about the cost coverage of preparative actions, extra buffers and improved resillience	• Keep in contact with the authorities and agree the actions on the basis of the agreements made

Actions to be taken following event

- **Return to normal operation**
- **Assess damage to infrastructure, vehicles and buildings**
- **Assess effectiveness of response**
- **Adapt / enhance according to lessons learned**

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6.5. TRaCCA managing extreme weather factsheets (reproduced from TRaCCA 2015a)

T1009 fact sheet: Management of summer conditions

Introduction & outline of task

The Tomorrow's Railway and Climate Change Adaptation research programme focuses on climate change adaptation for Great Britain's (GB) railway network. It is funded by RSSB (project reference T1009) and sponsored by the Technology Strategy Leadership Group (TSLG – a cross-industry group including Network Rail, train operating companies, etc).

As part of the T1009 programme, an "overseas analogue study" has been conducted to establish how the railway in Great Britain (GB) could learn from other countries' experiences in **weather resilience and climate change adaptation (WR/CCA).** The approach is outlined on the right.

Step 1: GB climate analogues: Which countries' present-day climates are similar to those projected for GB in the future (mid- and end-21st century)?

Step 2: GB railway analogues: Which countries' railways share key operating characteristics with the GB railway?

Key WR/CCA themes: summer management – how can summer conditions be mana

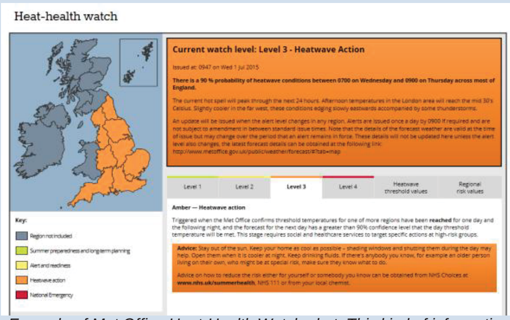
Strategic planning for hot weather

Overview

Ballast tamping, Southern England: this type of routine maintenance is restricted if hot weather happens / is forecast. © Network Rail 2015

- Management of hot weather requires **careful planning** and the **development of appropriate strategies** (e.g. emergency timetables, coordination with other operators, etc)
- **Strategies should be reviewed** after events, and **adapted in the light of new information**

Understand the weather hazard: Collect appropriate weather data, and develop appropriate systems for monitoring and warning



Example of Met Office Heat-Health Watch alert. This kind of information could be useful for the wellbeing of outdoor workers on the railway. © Crown copyright Met Office 2015

Understand the v
Assess the impact of
railway assets and

Heat-related track buckle, 2006.

Operational management of hot weather

Preparation

- ❖ In India, passenger thermal comfort studies have been carried out for key stations during summer
- ❖ Communication is essential for effective hot weather management (e.g. advising passengers to carry water, etc)

A crowded railway station. © Network Rail 2015

Weather-proofing infrastructure

- ❖ In Italy, rails in locations particularly sensitive to solar gain are painted white

Rails painted white, Italy. © Peter van der Linden

- ❖ In Belgium, the mec
of catenary wires ha
improved, to enable
adaptation to tempe

Overhead line with tension weights
© Network Rail

This fact sheet is one of a series of three on weather resilience and climate change a measures for flooding and winter weather management are available. Please contact

Step 3: Which countries are both climate analogues and railway analogues?

Only five countries were both climate and railway analogues ("combined analogues") according to our analysis: Belgium, France, Denmark, Germany and the Netherlands

Step 4: What WR/CCA measures are being used by other railways across the globe?

- Assessed via stakeholder engagement, literature review, and collation of learning from other large projects examining WR/CCA in transport (e.g. WEATHER, MOWE-IT)
- Compendium produced of all WR/CCA measures compiled from these sources

ged, strategically and operationally?

ulnerability:
hot weather on
d operations

© Network Rail 2015

Effective and timely maintenance supports and enhances preparedness

Maintenance of overhead line equipment on the East Coast Main Line. © Network Rail 2015

During **post-event repairs, incorporate measures to increase resilience**

Ensure any **lessons learned** after events are embedded into normal working practices

Take climate change into account when designing and siting new assets.

- *Some countries (including France, Germany, Spain, Hungary, Japan) use different stress-free temperature ranges to increase track resilience to hot weather*

Consider **different engineering solutions**, e.g.

- *Ground heat pumps can be used to remove heat from tracks / signalling at risk of overheating*
- *The use of slab track on certain rail lines (as in Germany, China, Italy, Spain, and Japan, for example) removes the need for ballast maintenance*

chanical system
as been
e better
erature variations

, West Coast Main Line.
2015

Weather-proofing rolling stock

- In Iran, generators can be fitted in each carriage on rolling stock to allow summer cooling
- In Spain and Italy, the cooling capacity on board rolling stock has been increased (e.g. more fans, air conditioning in driver's cab)
- For very hot climates, there are better specifications for air-conditioning on board rolling stock
- In Spain and Italy, the power output of diesel engines can be reduced, avoiding overheating and adjusting output to temperature
- Note that adaptive measures involving increased cooling would require offsetting of the associated increase in carbon emissions

System-wide factors

- Ensure that communication channels routinely support the sharing of information between industry organisations, between industry and customers (passengers and freight) – and, in extreme conditions, also with media and emergency responders
- Electronic equipment can be protected by installing appropriate cooling measures in lineside equipment cases, buildings housing signalling equipment, etc

Signal control board. © Network Rail 2015

- Effective ventilation systems are especially important for underground railways

adaptation measures collated during the T1009 Phase 2 project. Other fact sheets on
t us if you would like further information!

T1009 fact sheet: Management of winter conditions

Introduction & outline of task

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Step 2: GB railway analogues: Which countries' railways share key operating characteristics with the GB railway?

Key WR/CCA themes: winter management – how can cold weather, snow and ice be

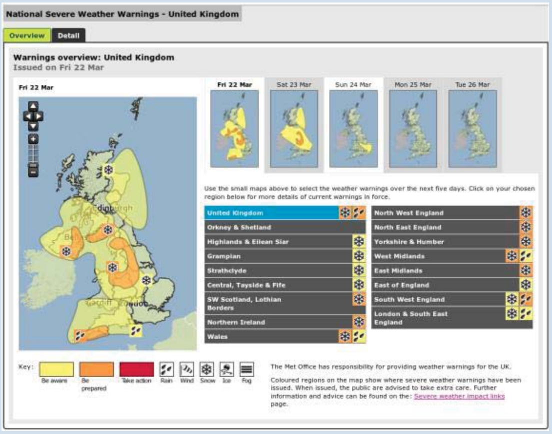
Strategic planning for cold weather, snow & ice

Overview

Snow in Sussex, SE England, January 2010. © Network Rail 2015

- Management of cold weather, snow and ice requires **careful planning** and the **development of appropriate strategies** (e.g. emergency timetables, coordination with other operators, etc)
- **Strategies should be reviewed** after events, and **adapted in the light of new information**

Understand the weather hazard:
Collect appropriate weather data, and develop appropriate systems for monitoring and warning



Met Office National Severe Weather Warning example.
© Crown copyright Met Office 2015

Understand t
Assess the impact of c
on railway ass

Snow in Aviemore, Scotland,

Operational management of cold weather, snow & ice

Training

❖ Train personnel to understand the specifics of winter operations

Switch heater inspection in snow. © Network Rail 2015

Preparation

❖ Obtain snow and ice melting equipment sufficiently far in advance of wintry conditions

❖ Ensure that track profile is free from obstacles (no low-hanging snow-covered vegetation, avoidance of ice formation at tunnel entrances)

Icicles in a tunnel. © Network Rail 2015

❖ Deliver spare parts (for assets sensitive to cold/snow/ice) to appropriate locations in advance of wintry conditions

Weather-proofing infrastructu

❖ Prevent snow build-up by using wind-inducing boards and snow blocking walls

❖ Remove snow from the track vi snow ploughs, snow blowers, a manually

❖ Install switch heaters

❖ In areas using third rail electrica systems, keep trains moving ac track overnight to reduce ice bu up

❖ Resistive heating of OLE to red ice build-up

❖ Use of anti-icing treatments in t rail electrical systems, to preven from bonding to the conductor r

This fact sheet is one of a series of three on weather resilience and climate change a measures for flooding and hot weather management are available. Please contact us

Step 3: Which countries are both climate analogues and railway analogues?

Only five countries were both climate and railway analogues ("combined analogues") according to our analysis: Belgium, France, Denmark, Germany and the Netherlands

Step 4: What WR/CCA measures are being used by other railways across the globe?

- Assessed via stakeholder engagement, literature review, and collation of learning from other large projects examining WR/CCA in transport (e.g. WEATHER, MOWE-IT)
- Compendium produced of all WR/CCA measures compiled from these sources

managed, strategically and operationally?

the vulnerability:
cold weather, snow and ice
ets and operations

January 2010. © Network Rail 2015

Effective and timely maintenance **supports and enhances preparedness**

Track maintenance. © Network Rail 2015

During **post-event repairs, incorporate measures to increase resilience** (e.g. install new components to higher standards)

Ensure any **lessons learned** after events are embedded into normal working practices

Track maintenance. © Network Rail 2015

re	*Weather-proofing rolling stock*	*Co-benefits*	*System-wide factors*
y- a nd al ross ild- uce hird nt ice ail	❖ Modify rolling stock to avoid snow / ice accumulation on undercarriage / in traction motors ❖ Modern rolling stock power electronics incorporate an 'ice mode' feature enabling units to operate more effectively when ice build-up affects the traction power supply  *Snow-caked locomotive, 2013. © Network Rail 2015* ❖ Modify the materials used in the manufacture of locomotives, and fuelling thereof, to enhance resistance to extreme cold ❖ Keep rolling stock in depots overnight	❖ Fit snow ploughs and brushes to locomotives to clear snow from rails *(benefits: rolling stock and infrastructure)*  *Snow plough. © Network Rail 2015* ❖ Keep platforms free of snow and ice *(benefits: passengers and staff)*	❖ Ensure that communication channels routinely support the sharing of information between industry organisations, between industry and customers (passengers and freight) – and, in extreme conditions, also with media and emergency responders ❖ Carry out preparatory inspections of assets (or a representative sample thereof) on a seasonal basis ❖ Carry out special maintenance inspections after severe weather events

adaptation measures collated during the T1009 Phase 2 project. Other fact sheets on s if you would like further information!

T1009 fact sheet: Management of flooding risk

Introduction & outline of task

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Step 1: GB climate analogues: Which countries' present-day climates are similar t those projected for GB in the future (mid- and end-21st century)?

Step 2: GB railway analogues: Which countries' railways share key operating characteristics with the GB railway?

Key WR/CCA themes: flooding – how can flooding be managed, strategically and op

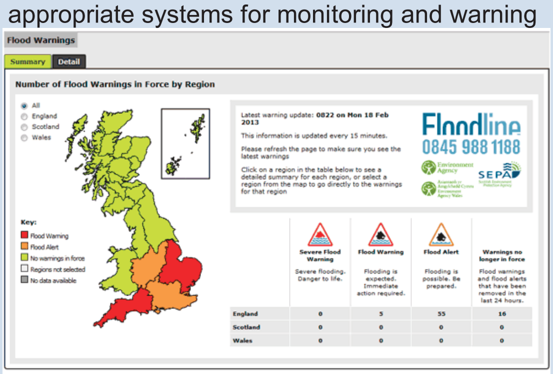
Strategic planning for flooding

Overview

Flooding affecting railway, Somerset, UK, Winter 2013/4. © Network Rail 2015

- Management of flooding requires **careful planning** and the **development of appropriate strategies** (e.g. emergency timetables, coordination with other operators, etc)
- **Strategies should be reviewed** after events, and **adapted in the light of new information**

Understand the weather hazard:
Collect appropriate weather data, and develop appropriate systems for monitoring and warning



Flood warnings example from Met Office website. The Met Office and Environment Agency / SEPA/ Natural Resources Wales work together to produce these. © Crown copyright Met Office 2015

In addition, **understand the source of the flood hazard**: surface water, fluvial (river), groundwater, or coastal.

Develop **flood hazard / flood risk maps.**

❖ *Many countries have developed these, including the UK, the Netherlands, Norway & Ireland.*

Understand t
Assess the impact of t
and o

Flooded lineside equipment in

Operational management of flooding

Training and personnel

❖ Have extra personnel on standby to help with additional duties during a flood event or to replace crews displaced by delayed/cancelled trains

❖ Understanding the source of the flood hazard can be relevant in responding to it

Flooded signal equipment at Maidenhead, Feb 2014. Groundwater flooding events like these result in water rising from beneath the surface rather than accumulating via runoff over the surface. © Network Rail 2015

Preparation

❖ Have operational flood response plans in place which can be used to prioritise use of limited resources during flooding events

❖ Be ready to issue flood warnings, or act upon warnings issued by other agencies, when requ

❖ Have flood mitigation equipment (e.g. water pu ready for use

This fact sheet is one of a series of three on weather resilience and climate change a measures for winter weather management and hot weather management are availab

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Step 3: Which countries are both climate analogues and railway analogues?

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- Compendium produced of all WR/CCA measures compiled from these sources

erationally?

he vulnerability:
looding on railway assets
perations

Somerset, UK. © Network Rail 2015

Effective and timely maintenance **supports and enhances preparedness** (e.g. clearing debris from culverts)

Lifting track to repair drainage pipe. © Network Rail 2015

During **post-event repairs, incorporate measures to increase resilience**

Ensure any **lessons learned** after events are embedded into normal working practices

Take climate change into account when designing and siting new assets.

❖ *In the UK, Network Rail has updated its drainage manual to incorporate a 20% increase in the estimated present day design flow.*

Consider **relocation / re-siting** for particularly vulnerable existing assets.

❖ *In locations vulnerable to flooding in the Netherlands, track has been elevated. Railways have been routed away from rivers.*

Consider **different engineering solutions**, e.g.

❖ *Slab track: may have better flooding resilience as no erosion/washout of ballast, and drainage channels can be incorporated into the design)*

❖ *Pile construction: may decrease the vulnerability of buildings containing important equipment (e.g. signalling)*

	Weather-proofing infrastructure	*System-wide factors*
e, ired mps)	❖ Install or deploy flood protection measures such as flood protection walls, inflatable dams or flood gates  *Inflatable dam in use, December 2013. © Network Rail 2015*	❖ In some places, the railway itself can act as a flood barrier ❖ Understand system interdependencies and effect of flooding on these (e.g. flood at electricity substation resulting in loss of traction power, even if the railway is not affected directly) ❖ Ensure that communication channels routinely support the sharing of information between industry organisations, between industry and customers (passengers and freight) – and, in extreme conditions, also with media and emergency responders

adaptation measures collated during the T1009 Phase 2 project. Other fact sheets on le. Please [contact us]() if you would like further information!

6.6. ISO Adaptation Standards

The International Standards Organisation is in the process of drafting a high-level International Standard - ISO14090 - on climate change adaptation. ISO14090, to be published in 2019, will provide a framework for adaptation and there are other ISO standards in draft to support ISO14090. These, together, will form a set of standards that can help society better prepare for the future climate and the different weather patterns this will bring.

ISO14090 itself will provide principles, requirements and guidelines for adaptation and will be supported by its 'daughter' standards on vulnerability assessment, climate finance and adaptation planning. Other more specific standards may follow. By using this suite of standards, any organization – not just railways – will, among others, develop a common understanding and use a common language for adaptation.

Expert opinion, however, sees the concept of adaptation and resilience building as potentially problematic. Whilst science tells us the climate is changing, railway operating, design and maintenance activities in the main use technical standards based on historical weather patterns.

However, this 'traditional' approach comes here with a benefit; as engineers use standards as a reference point, to be able to source and work to a standard is 'business as usual' for them. To have an ISO that covers, at high level, those things that need considering and how to set these into an adaptation plan, how to monitor and evaluate the plan's success and continue the 'plan, do review' cycle, will greatly assist us in adapting of infrastructure – and indeed society – to future changes in climate which will be manifest in new ranges of temperature, rainfall and other meteorological conditions.

One benefit already appearing is that users of the ISO standard will recognise how consistency in terminology and activity aids understanding and cooperation between the many 'actors' involved.

ISO14090 intends to cover, among other topics:

- Scoping and setting boundaries
- Climate effects: impacts, risk, vulnerability
- Opportunities
- Adaptation Planning
- Making use of existing policies, strategies and business plans
- Decision making
- Adaptive capacity
- Implementing, monitoring and evaluating progress against the plan
- Reporting and communication
- Stakeholder involvement
- Systems thinking

These topic headings can change as the document develops. For more information contact your National Standards Body.

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