



RAIL ADAPT

Adapting the railway for the future





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 knowledge and the tools to do it.

- 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 Board's 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 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 Boards 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.



Table of Contents

Introduction	1
Gauging current progress.....	3
The Rail Adapt framework.....	11
Developing an Adaptation Strategy	14
Hazards.....	16
Vulnerabilities	18
International Analogues	20
Consequences.....	21
Risk Representation.....	26
Risk Appraisal	27
Implementing Adaptation Plans	28
Option generation and assessment.....	29
Implementation of specific options	34
Managing and supporting adaptation.....	35
Organisational capacity.....	36
Assessing existing capacity	36
Building capacity	37
Conclusions and Recommendations.....	38
Appendices.....	40
Climate Change information signposting	40
Climate Adaptation project checklist.....	40
ISO Adaptation Standards.....	40



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 a potential loss of business to other modes of transport. In addition, the market is changing in other ways, with shifting populations, migration and economic development. Whilst this presents railways with opportunities for economic development, they will need to develop new thinking to remain sustainably cost-effective.

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.

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 good reputation as a reliable and environmentally sound transport mode. 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.

RailAdapt's vision is **"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 an organisation which is itself adaptive, and embeds the capacity for adaptation in all its 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 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 both informs, highlights and collates examples, bringing together best practice which can be tailored to local needs and strengths, whatever the resource limitations or scale.

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 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 held at a 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, 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 to ports. This has been supplemented by individual discussions with representatives of railway organisations and consultation on the draft report.

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.

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. How an organisation responds during extreme weather can therefore provide a useful indication of how well adapted that organisation is at present:

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 a good 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.





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 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 described in the box above.

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 by other rail or infrastructure providers, 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 between 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.

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.*

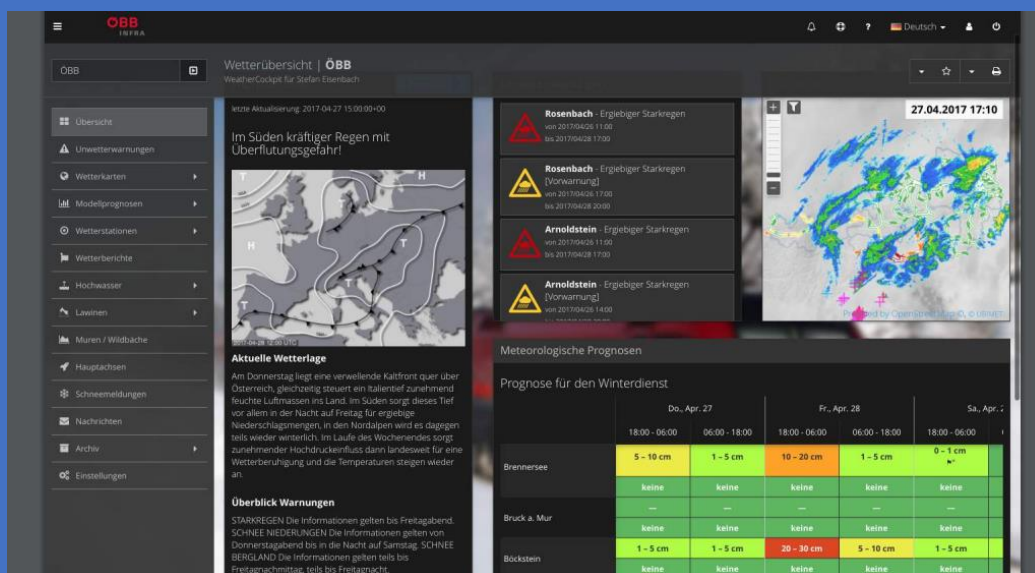
*The objectives of **infra:wetter** are to design, develop, provide and operate a flexible and extendable nationwide weather information system including a meteorological monitoring and warning network of weather stations and alarm systems, to observe local conditions and detect when hazards occur that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

Another important partnership is that between rail organisations and local authorities, road authorities, and other transport groups. Many disruptive events affect 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.

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.*

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, and/or ISO14000/9000, in risk management for safety and financial planning. 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.

It is critical to have strong and effective leadership and a shared vision in order 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. The existing expertise may reside in different units or departments within your organisation, or with external organisations, and these units will need to be brought together to forge 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 adaptation.

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 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

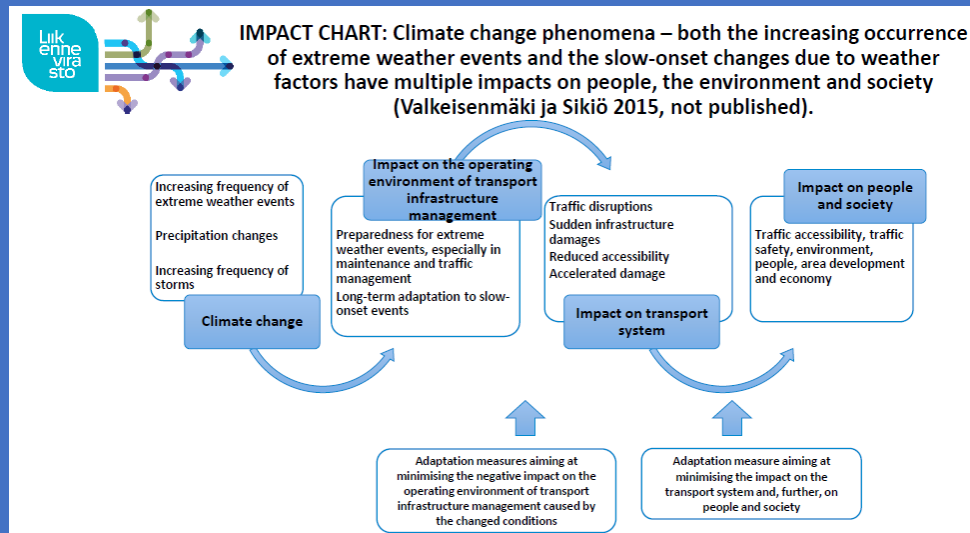


The Finnish Transport Agency (FTA) is a multidisciplinary expert organisation, contributing to the development of Finland's transport system through promoting traffic safety, sustainable development, and efficient travel. FTA are responsible for the management and maintenance of the Finnish rail network 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 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. 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 automatisisation 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.

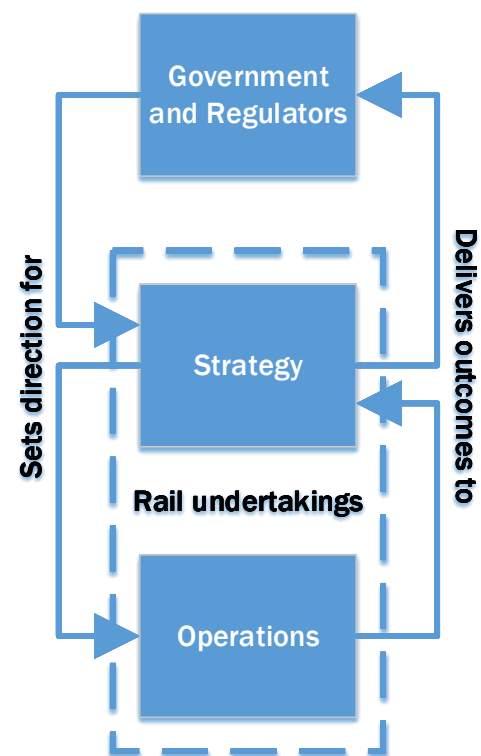
Key priorities for transport infrastructure management in Finland involve integrating adaptation into all activities, collecting data for vital risk assessment methods and harnessing the positive impacts of climate change. Rail specific adaptation includes strengthening and protecting structures, developing 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.

The Rail Adapt framework

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 sets 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 projects.

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

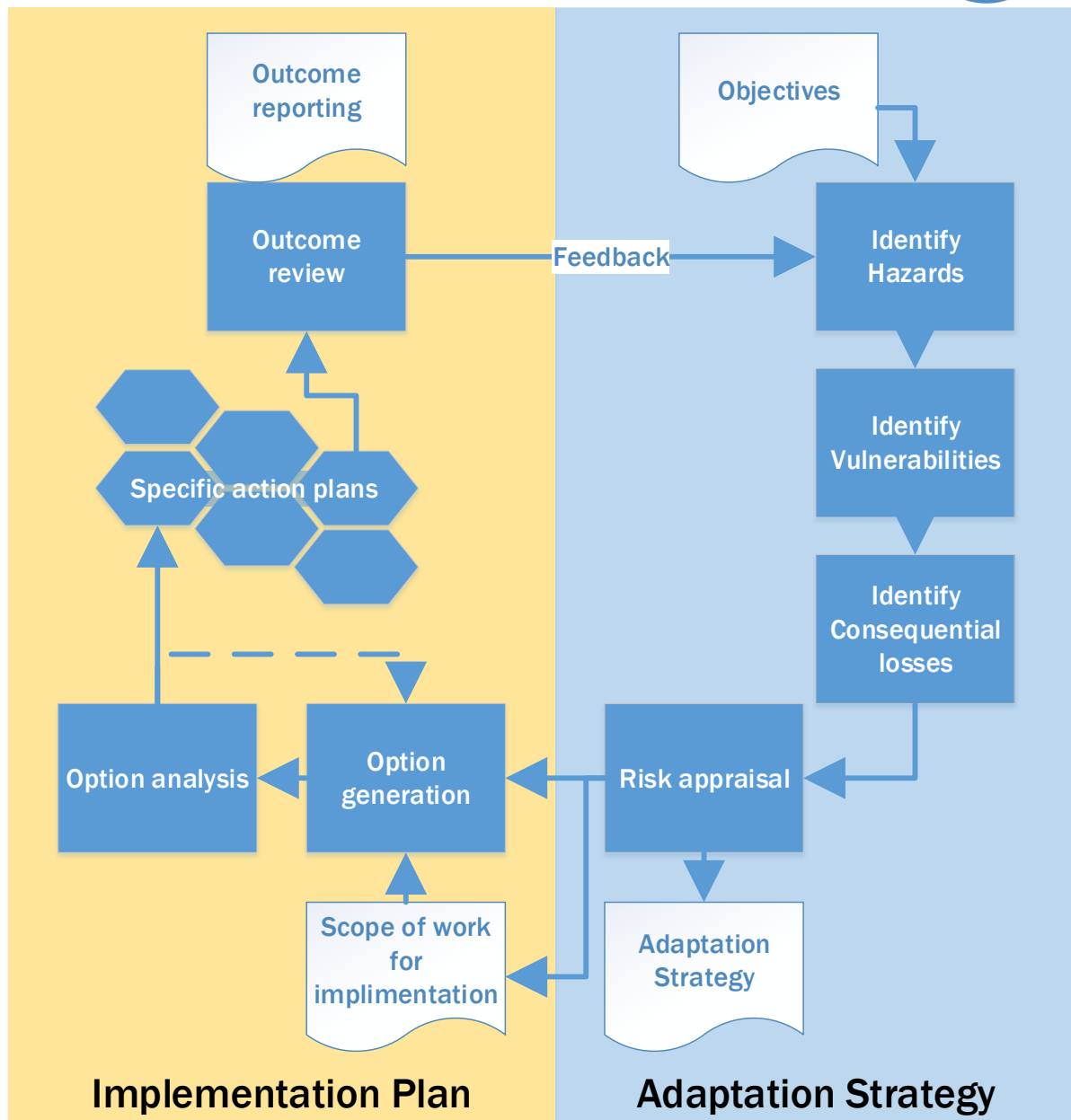


internal development of preparedness through adaptation so that the strategy and implementation process are focussed on long-term development for your organisation.

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 rail organisations such as Trafikverket in Sweden and the PIANC World Association for Waterborne Transport Infrastructure guidance to ports. It is also aligned with the structure of ISO55000. 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.



Developing an Adaptation Strategy

As has been raised previously 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.

Instead, in developing the Adaptation Strategy, the framework suggests a risk-based approach following the recommendations of the Organisation for Economic Cooperation and Development (OECD) in the development of policy. 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

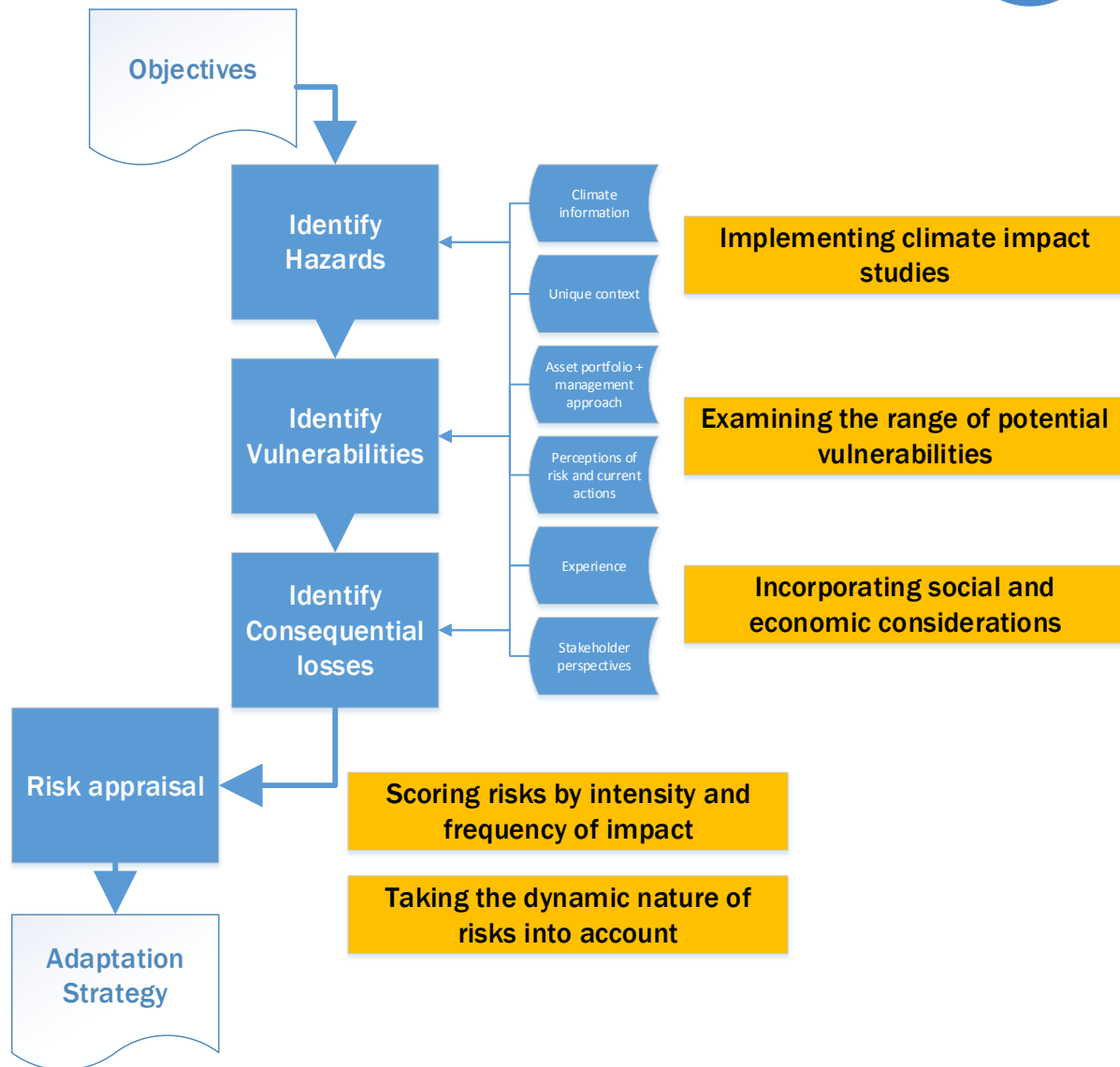
In 2009 the European Commission proposed a framework for climate change adaptation action which has 4 key elements:

- 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*

Most organisations will have existing risk management capabilities, which will already have experience of identifying and managing risks associated with safety and business continuity. Risk associated with climate change should be added and included within these processes if they are not already present.

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, 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 feeder line with a daily freight service may appear minor to an infrastructure manager but if that freight service provides fuel to an electricity generator the result may be widespread power failure, including to the railway itself, and therefore much more serious losses. Identifying such dependencies and interdependencies is an essential part of the assessment process.

[Box on TRaCCA WP4 interdependencies case study – fuel to power stations]



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.

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 box below).

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 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 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 compiled 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.

For example, in 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.

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.

Vulnerabilities

How climate and weather hazards impact on the railway, including assets, operations, services and passengers, is also 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.

Although challenging, the adaptation-planning progress can be undertaken even with imperfect information, for an action 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 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.

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 events, and the real causes of events, linked to good meteorological (and other scientific and engineering) understanding.

Diagrams such as those produced in the TRaCCA project (available through www.sparkrail.org) 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.



This example is for High temperature events (appendix G1)

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 current climate, with new vulnerabilities emerging that local networks may 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 proactively 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 overseas railway organisations, 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 RSSB-funded T1009 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.

[Box linking to TRaCCA vulnerability matrix]

Link to TRaCCA WP1 - Summary of information by climate variable (Appendix G1) and system or subsystem (Appendix G2) – demonstrate process for vulnerabilities

May also be useful to point to existing UIC series (high speed department) on flood hazards, strong winds, intercity natural risks

ARISCC vulnerabilities]

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) 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 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.

[California ART project <http://www.adaptingtorisingtides.org> box on expanding information in areas of unknowns – e.g. St Mateo bay bridge, community involvement on transport options]

There may also be ongoing current projects or developments within the organisation that will have 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 be a new vulnerability to services.

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 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: Russia – Russian Railways (RZD)

Asset Management and Extreme Weather Event Response



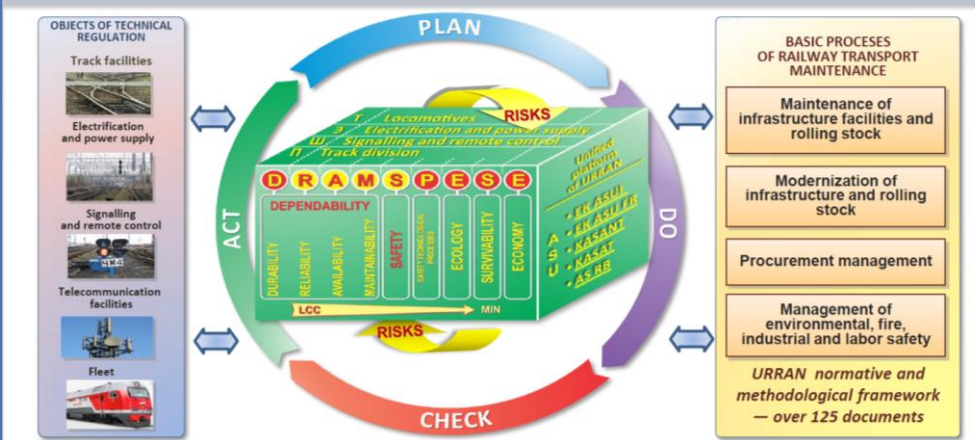
Russian Railways (RZD) manage rail infrastructure and operate passenger and freight train services in Russia. With over 100,000 track km, the Russian rail network is very extensive and therefore exposed to different climatic and geographic zones which present a complex array of hazards. Ice and snow 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.

Asset Management in RZD (URRAN System)



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 top 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.

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.

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, 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, D., Chapman, L., Petts, J. (2010) Assessing the impact of climate change on transportation: the need for an interdisciplinary approach. *Journal of Transport Geography*, 18, 331-335]

Jaroszweski, D., Hooper, E., Baker, C., Chapman, L., Quinn, A. (2015) The impacts of the 28 June 2012 storms on UK road and rail transport. *Meteorological Applications*. 22 (3), 470-476]

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 a hundred years. 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 than today. The probability of exceeding a certain threshold is nonstationary, which has the management implications that existing assets built to a certain standard in the past may now be more at risk, whilst building 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.

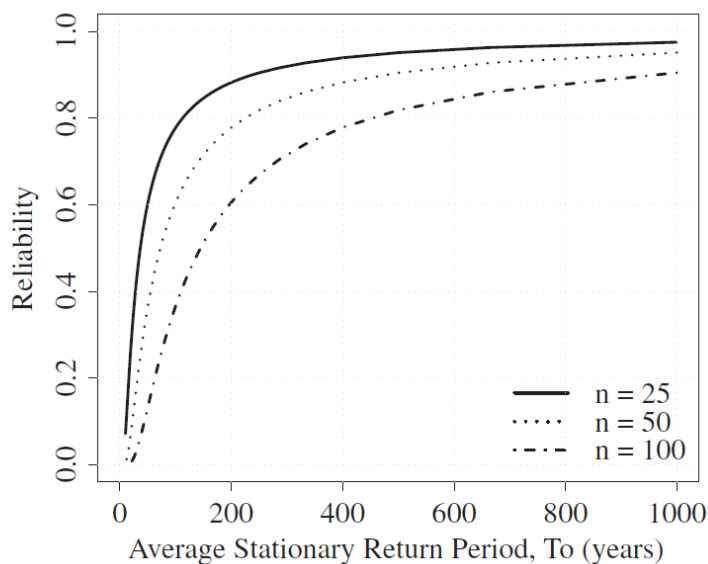


Figure 1. Reliability of a stationary system which is designed on the basis of an average return period T_o , corresponding to $n = 25$, 50, and 100 years.

Read, L. K., and R. M. Vogel (2015),
Reliability, return periods, and risk
under nonstationarity,
Water Resour. Res., 51, doi:10.1002/2015WR017089.

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.

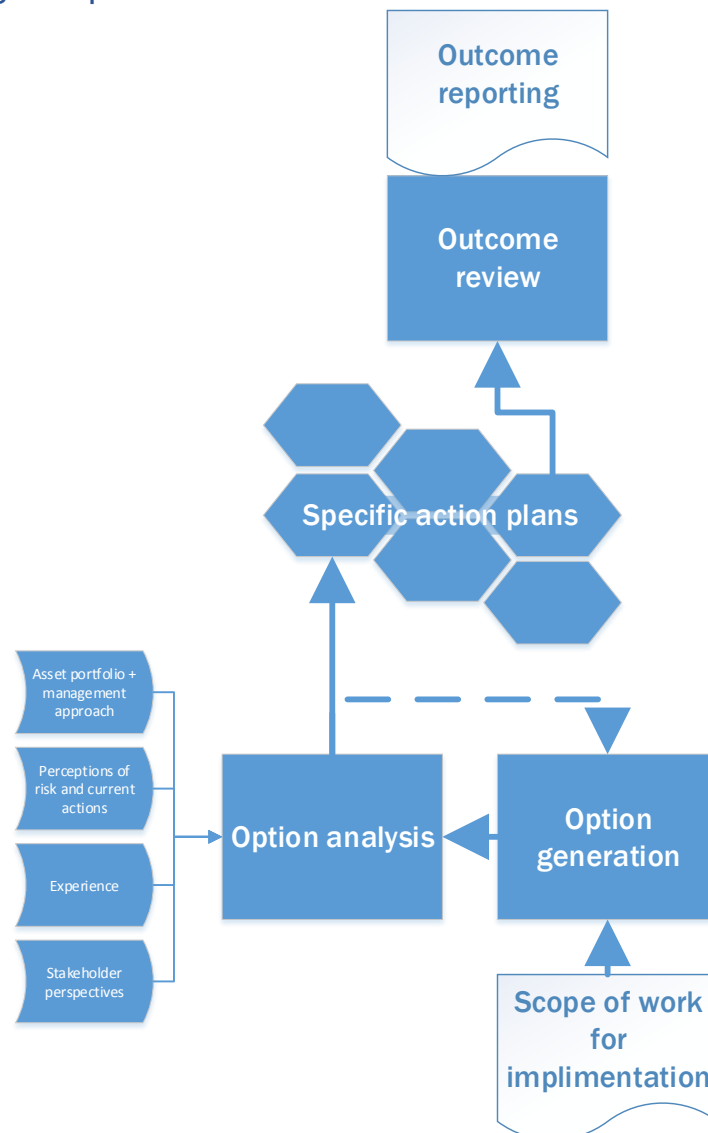
This process is likely to identify a variety of significant long-term impacts, which perhaps will develop slowly, and also immediate concerns about the impacts from extreme weather events that have occurred recently and may reoccur. It is important that both be given due consideration within the priorities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

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.

[ARISCC - 5.2 Guidance Document (p11-37) is a key section for adaptation best practice, in outlining procedures for an integrated natural hazard management – aimed at infrastructure managers (risk assessment and framework type material)]

[Role of development banks in setting minimum standards for adaptation, providing technical assistance and capacity building in developing countries.]

Implementing Adaptation Plans



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.**

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.

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 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 complimentary 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.

[Box on Austrian example of co-development of adaptation options]

When considering the options to address a specific risk it is also important to recall that there are many valid approaches to achieve resilience. Engineering solutions to make structures or services more robust, and therefore resisting failure under more extreme conditions, is one solution. Rerouting lines or renewing assets to a higher specification are other solutions. Other options that may be considered include back-up facilities, either permanent or temporary (along with plans for their deployment) in order to provide redundancy and / or plans and capability to repair the system rapidly in the event of a serious failure. In some circumstances, 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 is shared risks or dependency of service.

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 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.
- Where infrastructure cannot be viably protected from all failures resilience may take the form of pre-prepared repair plans and materials. Hazards forecasting and operational planning for transition to reduced operations or even controlled shut-down may facilitate such plans, linking engineering and operational aspects.

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.

[[box on TE2100 adaptive management approach](#)]

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 discounts the non-financial benefits, for example organisational reputation and impact to the wider community, of having a more resilient railway.

This illustrates that adaptation planning and implementation should not be undertaken as a separate activity, it 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 not 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. And payback periods of as low as 3 years even with discount rates of 3.5% being applied. This is important to justifying government expenditure on improvements.

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

[Box on the financial and insurance risk management for individual projects and how this needs to add up to a financial and insurance risk management for the organisation as a whole for adaptation]

[Plenty of material on recommended adaptation options / best practice ie. MOWE-IT and TRaCCA, case study on implementation actions]

Case Study: China – CRDC and CRRC

High Speed Rail infrastructure and rolling stock design



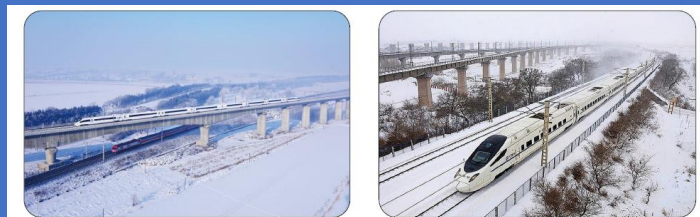
China Railway Design Corporation (CRDC) are an integrated survey and design consultant enterprise for the development of rail infrastructure in China. Most regions of northeast China frequently experience extreme cold conditions, including issues with ice and snow. In order to operate a safe and reliable 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.



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

[What will the future rail system look like? Material from Capacity4Rail, LivingRAIL, Arup 2050 vision report... adaptation options need to consider what rail 'system' will involve / how it may be used for lifetime of asset/development...]

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.

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.

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 climate in which it operates.

[WEATHER - Deliverable 7 - WEATHER Project Summary and Policy Conclusions

o Chapter 4 - Crisis and emergency management (p27-40) is useful for providing an operational framework for crisis and emergency management (EM), along with policy guidelines. Refer to 'D3 Innovative emergency management strategies' which is a more comprehensive breakdown of emergency management approaches, organisational and technological issues, and policy guidelines.]

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. Today, plenty of drivers exist: United Nations declarations, the Paris Agreement, the Sustainable Development Goals, the EU adaptation strategy, National Adaptation Plans, and also rules governing long-term investments in e.g. upgrades. Railways need to understand the implications of these drivers at Board level and to build the capacity to react, plan for and implement adaptation at policy levels, in strategic planning and in e.g. 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 organization's objectives, whilst IPCC 2014 [\[link\]](#) 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.

Assessing existing capacity

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

[Guidance for asset management maturity assessments can be found online, from the Institute of Asset Management here <https://theiam.org/knowledge/Asset-Management-Maturity-Guide>. Adaptation capacity assessment and guidelines for rail and other infrastructure operators can be found here <https://www.trioss.global/organisational-capacity-assessment-project>.]

ISO55001 assesses maturity on a six-point scale of 'maturity states' 1 (Innocent) to 6 (Excellent).

It is suggested the organization assesses how adaptation requirements, actions, decisions etc. are understood by decision-making personnel (and processes) at Regulator, Strategic and Operational/ Local levels [Simplified three-level diagram (Regulator-Strategy-Operations From Paris Meeting)].

The relevance of the hierarchy is that the parts of the organisation higher up give permission set the parameters within which to those below make decisions and to 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 it 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 form an organisational capacity-building plan.

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.

[TRaCCA 'whole system' diagrams here? Could show the seven-connected major sub-systems?]

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.

[Financial support – inc. observation that by incorporating adaptation in the normal process reduces the marginal costs because work is being done anyway, and reduces the overall (lifetime) costs because resilience avoids repair and early replacement]

[Role of re-insurance and finance of new projects as a driver for improving adaptation]

Conclusions and Recommendations

Rail Adapt has a vision that "an adaptive railway organisation is one that adjusts intelligently to the changing climate, delivering service sustainably with value for money"

The Rail Adapt vision and framework foresee not a 'special project' or new undertaking for rail organisations but adaptation integrated with business as usual.



Adaptation must involve people from across the organisation each considering it from their perspective. Adaptation must also involve partnerships with stakeholders, suppliers and user groups working together.

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.

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.

If a growing population is exacerbating the consequences of disruption then options to increase capacity with renewal alongside improved resilience may be appropriate.

The benefits of adaptation are improved resilience and a reduction in losses from future potentially disruptive events.

Appendices

Climate Change information signposting

[• Signpost to AR5 Adaptation Report Part B - Regional climate change summaries in Chapters 21-30. Useful chapters are 22-27 for Africa, Europe, Asia, Australasia, North America, Central and Southern America.

- IPCC SREX also worth a signpost – useful material on ‘extremes’
- May be worth a (brief) appendix pointing to these documents and some regional level studies (i.e. UKCP09) and material from ARISCC/EWENT/WEATHER – although I know we don’t want to restrict this to a European context
- UKCP18 will have a global (60km) output

<https://crudata.uea.ac.uk/~timo/climgen/national/web/>

ClimGen national average climate information website.

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.

Osborn, T.J., Wallace, C.J., Harris, I.C. et al. Climatic Change (2016) 134: 353. <https://doi.org/10.1007/s10584-015-1509-9>

Climate Adaptation project checklist

[A climate change risk management framework check-sheet for financial project support]

ISO Adaptation Standards

The International Standards Organisation is in the process of drafting a high-level International Standard - ISO14090 - on climate change adaptation. ISO14090 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
- Policy, strategy and planning
- 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 evolves.

