CIHT

Delivering a resilient transport network

Maintaining and future proofing highway infrastructure from extreme weather events

October 2024

Contents

Executive summary

The changing climate is having a major impact on the UK ageing infrastructure. Flooding, higher temperatures, storms, and severe weather are more common and accelerate failures and disruptions on the network. We therefore need a more resilient transport network to ensure reliability for people's travel and for goods deliveries. This requires future-proofing and maintenance of transport infrastructure.

Achieving resilience involves taking small, but prioritised, gradual steps. This can only be achieved through a UK-wide strategy to ensure that all critical infrastructure and the wider economy can withstand the impacts of climate change.

Urgency to act now and be prepared:
CIHT calls for adaptation and resilience to be made an immediate investment and policy priority, across all governmental transport strategies. There is a risk of significant and expensive infrastructure failures if resilience measures are not recognised as key strategic objectives now. Extreme weather events are happening with increased frequency and intensity – it is imperative that we act now to mitigate the risk of possible losses.

Funding for maintenance:
CIHT calls for investment in maintenance of our existing highways and infrastructure to ensure the continued and efficient use of our transport network. Incrementally adapting infrastructure and proactively maintaining it are crucial for extreme weather resilience and meeting decarbonisation goals.

Mandatory assessments of the current and future resilience of the infrastructure:
CIHT encourages the legislative road authorities of the UK to make it a statutory requirement for all transport asset owners to carry out transport resilience assessments. This will help to identify vulnerabilities in the network, prioritise remedial action and identify who should be responsible. This should also apply to neighbouring asset owners and utilities where risks and impacts are clearly inter-twined.

CIHT encourages the legislative road authorities of the UK to provide coherent and consistent guidance to the sector on how to undertake risk assessments on resilience.
There is a need to avoid different operators and asset owners developing their own internal assessments based on different assumptions, leading to non-transferable or non-sharable data.

The first part of this report highlights how future extreme weather will affect transport and stresses the need to prioritise adaptation and resilience in policy and investments. Preparing road infrastructure now is key to long-term resilience, saving costs, and protecting communities and the economy.

The second part offers an overview of the effects of extreme weather on the physical road infrastructure and a tool to guide practitioners in implementing ad hoc adaptation pathways, with case studies showing successful physical interventions that can mitigate the impacts of extreme weather events.

Foreword

Professor Phil Blythe,
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On behalf of the National Hub for Decarbonised, Adaptable, and Resilient Transport Infrastructures (DARe Hub), we were delighted to collaborate with the Chartered Institution of Highways and Transportation (CIHT) and its members to produce this report. We see the critical challenge of resilience as the one that has been least considered from a transport perspective, both in terms of the location and construction of new infrastructure and the future maintenance and adaptation of our existing road infrastructure. Obviously, the transport system is vital to our economy and society, and we are now regularly witnessing frequent disruptions and system failures caused by a decline in infrastructure condition and worsening weather extremes.

Our own weather models and those of our national and international collaborators suggest that climate-related weather extremes are increasing in both intensity and frequency and are likely to occur more often in worrying sequences or combinations. We only need to look at the floods in Europe in September 2024, leading to whole cities being evacuated, to get a glimpse of the scale of the challenge and possible future impacts on the UK. How do you recover a whole city? How much does that cost? What is needed to make those infrastructures more resilient to resist climate impacts and able to recover as quickly as possible from such extremes? We may even face harder questions in the future, such as do we abandon that city for good?

By engaging with expert stakeholders, ranging from road and infrastructure owners to material suppliers, consultants, and contractors who deliver the roads and their maintenance, we have received a significant body of evidence and advice from the sector that has helped us frame our thinking. Much of this is good practice that has been developed or adapted for the "now" period. This has been augmented by wider DARe Hub partners and academics who are delivering the science that underpins our research and challenge-function. What we have gleaned from this is that there is a need to reconsider and review the advice and "standards" that are given to the sector so those involved can make better and more informed decisions and consider trade-offs between the limited budgets that are available and what can be delivered, and thus what level of resilience they are designing to. This is critical – if infrastructure is built to nominally last for 50 years and the resilience of that will only reduce the risk of climate-related failures for weather extremes we are expecting in 20 years' time, we will soon find ourselves in a situation of needing significant and costly adaptations in the near future, which is likely to be much more expensive as a retrofit than factoring it in now.

This report is a significant body of work that provides guidance to industry and makes recommendations for government. Of these recommendations, we believe having a long-term plan and strategy for infrastructure resilience and building up knowledge to improve sector-wide understanding and develop recommendations for the future are of particular importance.

Introduction

Neil Johnstone
FCIHT, LSTSB

This report contains a strong message: the highways and transport sector needs serious prioritisation in this period of climate emergency. As ageing assets are increasingly exhausted in service of the economy, asset failures will only increase, unless there is a major realisation that the greater intensity and frequency of adverse weather events will see many vulnerable parts of our transport system reach their "tipping points".

Therefore, there is a pressing need to significantly enhance the country's current level of preparedness by investing in **resilience** and **adaptation**.

The urgency of this problem is a matter of concern for our profession. Through this report the CIHT aims to bring these issues to the attention of policymakers and decision makers in government. CIHT has a clear message: to be prepared for the severity of future weather impacts on our essential infrastructure, we need to **act now**. Without immediate action, the pathway to net zero for the transport sector will likely become an insurmountable task.

As the project lead on behalf of CIHT's Learned Society and Technical Strategy Board (LSTSB), I welcome the report at such a critical time. The excellent work of our in-house policy team, CIHT Partners, members' responses, and our advisory group, ably chaired by Professor Phil Blythe, has been invaluable. We are grateful not only to Professor Blythe, but also to his expert colleagues within the DARe Hub.

The recommendations in this report are supported by a comprehensive review of the resilience challenge, including data availability, modelling, appraisal, and case studies. As always, CIHT seeks to facilitate knowledge sharing and encourage collaboration to advance the "art and science" of our profession. A close examination of the case studies demonstrates that our industry possesses the skills and innovation needed to meet the adaptation challenge – provided there is stronger policy and funding commitment.

I encourage you to consider the findings of this report, driven by an imperative to ensure that transport networks are resilient and sustainable to serve our economy, communities, and natural environment. We need **action now** to make our highways network well adapted to address the climate impacts that are already locked in.

Definitions of decarbonisation, resilience, and adaptation

Climate change refers to long-term shifts in temperatures and weather patterns that are mainly driven by human activities. Burning fossil fuels like coal, oil, and natural gas releases greenhouse gases (primarily carbon dioxide CO2 and methane CH4), creating a barrier around the Earth that traps the sun's heat, raises temperatures, and modifies weather.[1] We can respond to climate change in different ways.

Decarbonisation aims to reduce greenhouse gas emissions by decreasing our reliance on fossil fuels. In 2019, the UK government committed to reaching net zero greenhouse gas emissions by 2050, based on 1990 levels, as part of the Paris Agreement.[2]

Adaptation refers to actions or processes that adjust a system so it can cope with the expected impacts of climate change.[3] Adaptation measures are urgent specific actions taken to minimise and avoid the harmful effects of climate change. It is a local, context-dependent process to reduce vulnerabilities.

Resilience is the property of a system to absorb, adapt to, or quickly recover from disruptive events. It involves anticipating and coping with shocks from hazardous climate events and recovering from their impacts efficiently.[4] Resilience builds resistance and recovery capability over time to cope with impacts and reduce risks, such as the ones associated with climate change, while adaptation is but one of the processes that helps improve resilience.[5] Building resilience is an ongoing process that enhances the ability to respond flexibly to extreme events and can only be fully understood within the specific local context. The 2021 publication by the Department for Transport (DfT) on Lessons learned from extreme-weather emergencies on UK highways has underlined the nature of the challenge now being faced across the UK by highways services and sets out key recommendations for change.

While decarbonisation aims to slow down climate change by reducing greenhouse gas emissions, adaptation and resilience (in combination) address the unavoidable impacts of climate change on human lives and activities. Decarbonisation tackles the core issue of climate change to reduce its effects. Adaptation and resilience make systems and society ready for future impacts and help them recover from the effects of extreme events. To be effective, it is critical to better understand what the likely extremes of climate weather will be like in the future and how this will impact individual infrastructures.

Since transport is the main source of greenhouse gas emissions in the UK, increased efforts are required to decarbonise the transport system in an effort to reduce the impacts of climate change. This will, however, be a lengthy process, during which time we will still face extreme weather events and temperature increases as consequences of climate change. Therefore, we must continue to intensify our efforts while also building appropriate resilience in our transport system to meet the challenges of change in the extremes of climate-related weather as we move forward.

[1] University of California, Berkeley, Burning of Fossil Fuels- Understanding Global Change
[2] United Nations Framework Convention on Climate Change (UNFCCC), The Paris Agreement
[3] Intergovernmental Panel on Climate Change (IPCC), SYRAR5 Glossary
[4] Mehryar, S. (2022), What is the difference between climate change adaptation and resilience? LSE Grantham Research Institute on Climate Change and the Environment
[5] Cañavera Herrera, J.S. (2019), Roads to adaptation: Understanding adaptation planning of urban road infrastructure. Cambridge University thesis

How to navigate this report

The topic of resilience is extremely complex, involving multiple owners and interests. CIHT acknowledges that creating resilience in the transport sector requires considering the interplay of many factors and exploring the way transport is planned, delivered, and provided as a service. The aim of this work is to support strategic thinking in decision making by highlighting the challenges and priorities identified by the industry that the government should take into account when directing national policy and investment. It also builds on the work that is currently being undertaken by the sector to ensure that we adapt our road infrastructure and incorporate resilience.

This report is divided into two parts:

PART A

is aimed at the government, the DfT, and local authorities. It shows how future weather events will impact the transport sector and calls for adaptation and resilience to be emphasised as a policy and investment priority. It argues that adapting road infrastructure now is crucial for long-term resilience, cost savings, and community and economic protection. Other issues, such as the reputational damage of failed infrastructure, are not considered here.

PART B

is aimed at practitioners in the supply chain and managers in highway authorities. It provides information and tools for identifying physical interventions to implement through an adaptation pathway. This part also includes case studies showcasing examples of successful adaptations to extreme weather challenges.

The two parts are intended to be complementary, and CIHT encourages readers to go through them both to have a holistic view of the issue.

This report was created through a series of engagement activities involving online and in-person workshops between January and May 2024, a call for evidence in March 2024, and the support of an advisory group representing the CIHT Partnership Network, the CIHT Technical Champions and the DARe Hub.

PART A

Is the highways and transportation sector ready?

It has long been established that a lack of maintenance and renewal of the UK's road infrastructure impacts the provision of transport services. The ageing infrastructure is also increasingly being exposed to the risk of wear and tear from extreme weather conditions.

The increased frequency and intensity of extreme weather events are accelerating the deterioration of our roads and the ability of the sector to deliver seamless services to all communities.

The 2017 UK Climate Change Risk Assessment (CCRA) reported that 6,600km (1.5%) of the UK road network is in areas that are vulnerable to flooding, claiming that this could increase to between 2.3% and 3.9% by the 2080s.[6] In the latest CCRA in 2022, the risk of transport infrastructure failing due to heavy rain has been classed as High to Very High.[7] This generates more than a maintenance problem as extreme flooding can completely wash away and destroy infrastructure. We are not seeing this impact often in the UK as of yet; however, as extremes of weather become greater, this is likely to occur more, making some infrastructure difficult to either protect or continually rebuild. It is urgent that nationally we begin to identify vulnerable infrastructure and determine what mitigations may be available or whether over time we may have to lose the asset.

It is not only extreme weather events that can lead to road closures and flooding. With an ageing asset, we are facing the possibility of service-critical and expensive infrastructure failures around the country due to a lack of timely maintenance.

Higher temperatures pose another set of challenges for our roads, from melting and softening of materials to buckling bridges. What's more, it is clear the UK is experiencing, on average, more frequent periods of hot weather; the number of "hot" days (daily maximum 28°C) has more than doubled for the most recent decade, and "very hot" days (30°C) have more than trebled.[8]

Working with uncertainty

The sector faces challenges due to the unpredictability of weather patterns and their effects on infrastructure. Furthermore, understanding the scale of the threat posed by climate change is arduous work. Due to the "moving target" created by the Earth's rapidly changing climate, predicting future extreme weather patterns is increasingly difficult, and the most extreme scenarios that this could potentially produce, even today, have not necessarily occurred yet.[9] Transport professionals must navigate complex and unstable environments influenced by:

Weather variability: Extreme weather events vary in frequency, intensity, and duration based on location. Climate models predict an increase in extreme weather events such as heavy precipitation, heatwaves, and coastal flooding, but the exact timing and severity are difficult to forecast accurately.

Infrastructure vulnerability: Different types of road infrastructure have different vulnerabilities. Age, location, type of materials, frequency of renewals, and maintenance influence the way assets will react to and withstand different weather conditions.

Data availability: Data on the condition of assets, weather forecasts, and the impacts weather events will have on roads is difficult to collect and not accessible to all owners, operators, or highway authorities. It is a priority that we identify the data required and ensure that it can be collected and disseminated effectively.

[6] Steen B., Chowdhury, R., Fletcher, A., Standing-Tattersall, C. (2022), Climate change adaptation and transport infrastructure: A rapid evidence assessment, NatCen Social Research

[7] UK Climate Change Risk Assessment 2022

[8] Met Office (July 2024), Temperature extremes and records most affected by UK's changing climate

[9] Lee, H.S., Fowler, H.J., Davies, P. The climate is changing so fast that we haven't seen how bad extreme weather could get, The Conversation (July 2024)

Economic impacts: Costs from weather damage and maintenance are significant but hard to predict, depending on event intensity and the impact on the infrastructure. Economic impacts should look at the community level as well as at the national level and also consider productivity, health, wellbeing, and reputational damage.

Risk of maladaptation: [10] Uncertainties also exist on how effectively adaptation measures can be implemented and how successful they will be. The success of adaptation measures depends on factors such as funding, technology, and political will. There is also a need for a regional approach to understand the geological and meteorological forces at play and create regionally appropriate solutions.

The case for investing in resilience to extreme weather events

CIHT calls for a long-term infrastructure strategy, of at least 10–20 years, that includes adaptation and resilience to climate change as a key investment priority. To support the investment strategy, we need to research and collect the necessary evidence and ensure a narrative exists that all stakeholders understand and will buy into. The strategy should focus on preventative maintenance, support the supply chain, and view critical infrastructure (road, rail, and power supply, distribution networks and digital networks) as a connected system. We recognise the challenge of this as long-term resilience requires investment beyond the current financial period.

In particular we call on the UK governments (including devolved) to:

- Make adaptation and resilience a policy and investment priority to deliver economic stability and growth.
- Make it a statutory requirement for all transport asset owners to carry out transport resilience assessments. This will help to identify vulnerabilities in the network, prioritise remedial action and show who should be responsible.
- Set up a dedicated fund to understand the type of impacts now occurring, and support projects to mitigate such vulnerable areas.
- Build adaptation and resilience into the transport system and wider economy to create a competitive environment that supports innovation and investments in high-quality jobs.
- Invest now in preventative maintenance and incremental adaptation measures to lower future costs associated with repairs, avoiding expensive infrastructure losses and saving money for future investments.
- Have at least a five-year commitment to funding local roads maintenance and renewal (a local roads investment strategy).

The government should support the necessary legislative and physical environment changes to enable trialling and use of innovative products and techniques across the strategic and local highways and transport networks.

In our research for this report, it has become evident that design standards should be reviewed to ensure that they support resilience and adaption measures.

Economic and social activities require a seamless, reliable, and safe transport network and services. The current road infrastructure in the UK is not fit to withstand the threats posed by climate change and extreme weather events.

Preparing for the future involves both tackling climate change through decarbonisation and adapting to extreme weather impacts. Substantial economic and social benefits from transport will be lost if the infrastructure is not resilient to extreme weather.

[10] In this report the term maladaptation refers to the unintentional negative result of an adaptation measure that has unwittingly worsened the vulnerability of the infrastructure

Diagram 1. The benefits of investing in adaptation and resilience

Benefits:

Avoided cost

- Lower immediate cost of damage and repair
- Avoided lost revenue
- Avoided cost of compensating consumers
- Avoided social and safety cost

Increased private investments

- Support digital developments
- Green energy and jobs
- Service reliability to boost trade and the movement of goods

Boost to innovation

- New materials and construction products
- Communications and data sharing
- Digital twins of physical infrastructure

Benefits to local communities

- Avoided or minimised journey disruptions
- Resilient transport infrastructure increases trust and credibility for local businesses
- Increased property value
- Protection of vulnerable communities

How much has extreme weather cost the highways sector so far?

- In the UK and Northern Ireland repair costs related to floods and heavy precipitation were estimated at £50 million per year in 2010, increasing at £500 million per year by the 2040s.
- The cost of bridge repairs from extreme weather can be between 2 and 10 times the actual cost of the bridge.
- Local highway authorities reported more than £250 million in damages to roads, bridges, public rights of way, and drainage systems following the 2015–2016 winter floodings.

The costs and data mentioned cover the period from 2010 onwards. Readers should note that costs are now higher due to inflation.

Current barriers in the sector

Through our call for evidence, we have identified that the sector already deploys great skills to combat the impacts of extreme weather and to build in resilience and adaptation. However, the variety of approaches still appears to be fragmented and many barriers and challenges have been identified.

Table 1. Barriers to building resilience and adaptation

URGENCY AND AWARENESS

Lack of urgency
There is a general lack of urgency in addressing these issues.

Understanding impacts
There is limited understanding of the cascading impacts on other infrastructure and systems (such as water, power, other transport lines).

Long-term commitment
There is a lack of sustained political attention and evidence-based decision making.

INFRASTRUCTURE AND ASSET MANAGEMENT

Ageing assets
There is limited funding for maintenance of ageing infrastructure.

Whole-system approach
A framework or tools for holistic infrastructure asset management is lacking.

Impact assessment
There is insufficient assessment of the impact points of integrated systems (water, roads, rail) affected by the same weather event.

KNOWLEDGE AND DATA

Knowledge gaps
Particularly identified in areas such as sustainable drainage systems (SuDS) and infrastructure conditions.

Data set accessibility
Costs and restrictions (GDPR or business reasons) limit access to essential data sets or lack of data available.

Integrated data sets
A lack of integrated data sets prevents proper assessment of links between assets, such as pavements, drainage, and structures.

Weather forecasting models
Better access to local weather forecasting models is needed for accurate predictions.

COLLABORATION AND ENGAGEMENT

Transdisciplinary collaboration
Greater engagement is needed with landscape architects, environmental engineers, emergency managers, and other disciplines in the general design and maintenance of all types of building and infrastructure.

Road authorities
Collaboration between local and trunk roads authorities and among neighbouring authorities is uncoordinated across the country.

Utilities
Closer working is needed on new works and routine and adaptive maintenance projects to ensure interactive impacts arising from possible worsening weather impacts are identified and managed.

Recommendations of PART A

- **Urgency to act now and be prepared:**
  CIHT calls for adaptation and resilience to be made an immediate investment and policy priority across all governmental transport strategies. There is a risk of significant and expensive infrastructure failures if resilience measures are not recognised as key strategic objectives now. Extreme weather events are happening with increased frequency and intensity – it is imperative that we act now to mitigate the risk of possible losses. An associated communications strategy should, in parallel with a new policy, be sustained to rapidly boost industry awareness.

- **Funding for maintenance:**
  CIHT calls for investment in maintenance of our existing highways and infrastructure to ensure the continued and efficient use of our transport network. Incrementally adapting infrastructure and proactively maintaining it are crucial for extreme weather resilience and meeting decarbonisation goals. There needs to be a dedicated fund to support projects to mitigate such vulnerable areas.

- **Mandatory assessments of the current and future resilience of the infrastructure:**
  CIHT encourages the legislative road authorities of the UK to make it a statutory requirement for all transport asset owners to carry out transport resilience assessments. This will help to identify vulnerabilities in the network, prioritise remedial action and identify who should be responsible. This should also apply to neighbouring asset owners and utilities where risks and impacts are clearly inter-twined.

- **CIHT encourages the legislative road authorities of the UK to provide coherent and consistent guidance to the sector on how to undertake risk assessments on resilience.**
  There is a need to avoid different operators and asset owners developing their own internal assessments based on different assumptions, leading to non-transferable or non-sharable data.

- **Building a nationwide leadership:**
  Making it mandatory to include resilience as a strategic objective for all asset owners and transport operators in 2024 and onwards. Achieving resilience involves taking small, but prioritised, gradual steps. This can only be achieved through a UK-wide strategy to ensure that all critical infrastructure and the wider economy can withstand the impacts of climate change. A great example of this is the recently established Adaptation, Biodiversity and Climate Change (ABC) Board, within the UK Road Leadership Group, that aims to understand how our road networks operate and adapt to new pressures such as changing weather conditions, habitat preservation, and ecology protection.

- **Trial innovative products and techniques:**
  Governments should support the necessary legislative and physical environment changes to enable trialling and use of innovative products and techniques across the strategic and local highways and transport networks.

PART B

Effects on the road infrastructure from different extreme weather events

Weather events impact road infrastructure based on both their intensity and the asset's current condition. For highway authorities, it is important to know what risks future weather events can pose to the road infrastructure.[11]

Table 2 provides a high-level overview of the impacts of different weather events and some possible solutions to consider. The reader should note that the application of these is dependent on local circumstances and should consult further guidance[12] for more information.

Table 2. Impacts on road infrastructure of extreme weather events

Weather variable	Impacts on road infrastructure and possible solutions
RAIN AND FLOODING **(includes river flooding, coastal flooding, and heavy rainfall flooding).**	**DRAINAGE SYSTEMS OVERWHELMED** Impact **Inadequate and exceeded drainage capacity and poor maintenance lead to surface water on roads.** Solutions **Drainage systems improvements and maintenance:** Upgrades including SuDS (flood walls with non-return flap valves). **SuDS and raingardens:** Introduce sustainable drainage solutions to reduce stormwater run-off, increase infiltration, and help mitigate impacts of polluted run-off. **Upsizing drains:** Increase the size of drains and culverts to handle higher water volumes. **Retention ponds:** Construct ponds, new streams, or reservoirs to temporarily store excess water during heavy rain. **Smart drainage systems:** Use sensors to monitor drainage performance and optimise flow. **Proactive surface water management plans:** Move away from reactive surface water management plans and include fragmented drainage management assessment.

[11] Bles, T. et al. (2015), ROADAPT: Roads for today, adapted for tomorrow, CEDR

[12] Design Manual for Roads and Bridges (DMRB), Standards For Highways

Weather variable	Impacts on road infrastructure and possible solutions
RAIN AND FLOODING (includes river flooding, coastal flooding, and heavy rainfall flooding).	**INCREASED PRESSURE ON RIVERBANKS** Impact **Intense rainfall can erode riverbanks, threatening road stability.** Solutions **Reinforced embankments:** Use geotextiles or gabions to stabilise riverbanks. **Vegetation:** Plant native vegetation to prevent erosion. **Riverbank monitoring:** Regular inspections to detect signs of instability. Use remote sensing technology to provide alarm of movements. **ROAD FLOODING FROM ADJACENT RIVER FLOODING** Impact **Flooded roads disrupt traffic, damage vehicles, and pose safety risks.** Solutions **Elevated roadways:** Raise roads above flood-prone areas. **Flood barriers:** Deploy temporary barriers to prevent water from inundating roads. **Upstream land management:** Use nature-based solutions such as tree planting and managed flooding to prevent waters reaching the road. **Emergency pumping stations:** Quickly remove floodwater from roads. **EROSION OF EARTHWORKS** Impact **Soil erosion undermines embankments and slopes.** Solutions **Prioritisation:** Use geotechnical data and mapping with local knowledge to identify high-risk sites. **Geosynthetics:** Reinforce soil with geogrids or geotextiles. **Bioengineering techniques:** Use vegetation to stabilise slope soil and prevent erosion. **Rock armouring:** Place rocks or concrete blocks to protect against erosion.

Weather variable	Impacts on road infrastructure and possible solutions
RAIN AND FLOODING (includes river flooding, coastal flooding, and heavy rainfall flooding).	**POWER LINES AFFECTED** Impact **Flooded roads can damage power lines and disrupt electricity supply.** Solutions **Elevated power lines:** Raise power lines above flood levels. **Underground cabling:** Bury power lines to protect them from flooding (assuming sealed). **Quick restoration plans:** Use efficient repair strategies for power outages. **PREMATURE DETERIORATION OF ASSETS** Impact Prolonged inundation or damp weakens road materials. Solutions **Durable materials:** Use weather-resistant asphalt, concrete, and coatings. **Regular inspections:** Assess pavement condition after floods. **Timely repairs:** Fix damage promptly to prevent further deterioration. **POTHOLES AND SURFACE FAULTS** Impact Water infiltration causes pavement distress. Solutions **High-quality sealants:** Seal cracks to prevent water penetration. **Proper compaction:** Ensure proper compaction during construction. **Resilient pavement design:** Use mixes resistant to freeze–thaw cycles.

Weather variable	Impacts on road infrastructure and possible solutions
RAIN AND FLOODING (includes river flooding, coastal flooding, and heavy rainfall flooding).	**BRIDGE SCOUR AND FAILURE** Impact **Fast-flowing floodwater erodes bridge foundations.** Solutions **Scour protection:** Install riprap (a layer of stones that protects soil from erosions in areas of high or concentrated flows of water) or other protective measures around piers. **Bridge inspections:** Make frequent checks for signs of scour. **Technology monitoring:** Use emerging technologies to monitor conditions remotely. **Emergency closure plans:** Take swift action if scour threatens bridge stability. **EROSION OF PAVEMENTS** Impact **Water undermines road surfaces.** Solutions **Permeable pavements:** Allow water infiltration to prevent surface erosion. **Edge drains:** Collect water before it reaches the pavement. **Regular resurfacing:** Maintain pavement integrity.

Weather variable	Impacts on road infrastructure and possible solutions
RAIN AND FLOODING (includes river flooding, coastal flooding, and heavy rainfall flooding).	**POSSIBLE CAUSE OF ROCK/LANDSLIDE** Impact Saturated soil increases landslide risk. Solutions **Slope stabilisation:** Reinforce slopes to prevent landslides. **Early warning systems:** Monitor slope movement. **Vegetation management:** Prevent root decay that weakens slopes. **RAINFALL MODELLING AND DESIGN** Impact Varying approaches to dealing with projected rainfall; often one-size-fits-all approach. Solutions Do more detailed modelling of local rainfall and flooding conditions at an early design stage to produce project-specific projections.

Weather variable	Impacts on road infrastructure and possible solutions
INCREASED TEMPERATURES	**LESS SHADING DUE TO LESS VEGETATION** Impact Lack of shading and cooling effects from vegetation as higher temperatures affect plantlife. Solutions Plant more heat and drought-resistant trees and vegetation along roadsides. These green buffers provide shade, reduce the urban heat island effect, enhance comfort for pedestrians and cyclists, and provide habitat for biodiversity. **MATERIALS MELT OR BECOME SOFT (BLEEDING)** Impact Increased temperatures melt pavement materials. Solutions Use polymer-modified asphalt binders that have higher softening points. These binders resist softening and bleeding. Additionally, cool pavements (high solar reflectance) reduce surface temperatures. Investigate asphalt rejuvenators that increase thermal resistance properties.

Weather variable	Impacts on road infrastructure and possible solutions
INCREASED TEMPERATURES	**INCREASED DUST** **Impact** An increase in temperatures can reduce moisture and cause droughts. **Solutions** Apply dust suppressants or stabilisers to road surfaces. Regular street sweeping and vegetation management can minimise dust accumulation. Plant more heat and drought-resistant trees and vegetation along roadsides to secure loose soils. **MATERIAL SHRINKAGE OR EXPANSION** **Impact** Temperature increases reduce moisture in the atmosphere and materials, causing shrinkage or making them melt and expand. **Solutions** Design and install new expansion joints in concrete pavements and use flexible materials for asphalt pavements. These allow for thermal expansion and contraction without damage. Maintain and clean existing joints. Monitor thermal properties of roads to establish when dangerous expansion is occurring. **BRIDGES BUCKLE** **Impact** Increased temperatures make materials softer and cause bridges to bend. **Solution** Install new expansion joints and/or bearings in bridges to accommodate thermal movements. Regular inspections and maintenance are crucial to detect early signs of buckling. Monitor thermal properties of structures to establish when dangerous expansion is occurring. **RUTTING (DEPRESSIONS OR GROOVES ON SOFTER SURFACES)** **Impact** With increased temperatures, pavement materials become soft and malleable, for example under the weight of vehicles. **Solutions** Use rut-resistant asphalt mixes with modified binders. Proper compaction during construction prevents rutting. Regular maintenance and overlaying damaged sections help maintain road integrity. Consider concrete pavements.

Weather variable	Impacts on road infrastructure and possible solutions
SNOW AND ICE	**EXPANSION OF MATERIALS (CAUSING CRACKING)** **Impact** When snow and ice melt, the water infiltrates cracks and pores in road materials. During freezing temperatures, this water expands as it turns into ice, exerting pressure on the materials. **Solutions** **Permeable pavements:** Use permeable materials that allow water to drain through the pavement, reducing the risk of expansion-induced cracking. **Expansion joints:** Install expansion joints in concrete pavements to accommodate thermal movements without causing cracks. **Regular maintenance:** Fill existing cracks promptly to prevent water infiltration and subsequent expansion. Use digital technology to optimise the spreading of gritting salts across the network, offering efficiency savings. **EFFECTS OF GRITTING ON ROAD SURFACE MATERIALS** **Impact** Gritting involves spreading rock salt (sodium chloride) on roads to prevent ice formation and melt existing ice. **Corrosion:** Rock salt can be corrosive to road surfaces and nearby structures. It destabilises porous materials, leading to increased wear and tear. **Environmental concerns:** Excessive use of rock salt can harm vegetation, soil, biodiversity, and water bodies. **Solutions** Do more detailed modelling of local rainfall and flooding conditions at an early design stage to produce project-specific projections. **Eco-friendly alternatives:** **Calcium magnesium acetate (CMA):** Environmentally friendly de-icer that reduces corrosion. **Beet juice mixtures:** Beet juice combined with salt lowers the freezing point and reduces environmental impact. **Reduce the impact of snow and icing on surfaces:** Use pre-wet spreaders or de-icer instead of overspreading salt, which can damage road materials.

Weather variable	Impacts on road infrastructure and possible solutions
WIND	**GENERAL PHYSICAL INTERVENTIONS** **Vegetative windbreaks and buffer zones:** Plant trees or install barriers to reduce wind impacts (such as blowing debris or wind damage to properties). **Strengthened roadside structures:** Reinforce signs, guardrails, and lighting poles. **Flexible roadway materials:** Use materials that can withstand wind-induced movement. **GENERAL ASSET MANAGEMENT AND MAINTENANCE** Incorporate climate projections on winds into design standards and inspection assessment criteria. Carry out regular inspection of roadside structures. Promptly repair damaged signs and guardrails after storms.

Weather variable	Impacts on road infrastructure and possible solutions
SEA LEVEL RISING	**ROADS FLOOD** **Elevated roadways:** Construct elevated or raised roadways above the projected flood levels. This prevents direct inundation during high tides or storm surges. **Permeable pavements:** Use permeable materials that allow water to drain through the road surface. These pavements reduce surface run-off and minimise flooding. **Tidal gates and drainage systems:** Install tidal gates and efficient drainage systems to manage water flow during extreme events. Consider the locations of new infrastructure and avoid high-risk locations. Accept that not all infrastructure can be protected and reinstalled as sea levels rise.

CIHT

Adaptation pathway for highway infrastructure

An adaptation pathway is a series of interlinked options that can be applied at different moments in time to flexibly solve a problem. In the specific case of climate change, adaptation pathways have been defined as:

"a sequence of actions, which can be implemented progressively, depending on future dynamics in order to assist adaptation to climate change. The development of adaptation pathways can assist infrastructure owners and operators to adapt their existing assets and networks to maintain desired operational performance under future and yet unknown climate conditions" [13]

An adaptation pathway approach helps asset owners develop a flexible strategy that maintains operational performance and good asset condition – within an uncertain climate – by combining long-term resilience with short-term adaptation objectives and actions.

Adaptation pathways can be thought of as flexible risk management and option planning frameworks. This can help make progressive decisions and switch to different solutions in case the ones implemented are not working as desired.

Adaptation pathways also help to overcome the limits of a single adaptation measure and possibly avoid maladaptation (e.g. unexpected and negative outcomes of adaptation measures), and they allow practitioners to feed in more information (as it becomes available) and switch path, if required.

The concept components of adaptation pathways:

- Adaptation tipping points: Points at which a strategy or intervention is no longer working or no longer sufficient and alternative options have to be considered.
- Acceptable levels of risk: In order to minimise costs of interventions or changes in solutions, it is important at the outset to define acceptable levels of risk under which the infrastructure can still run and deliver its service safely. This must take into account the changing predictions of what will constitute the climate extremes of weather in the future.
- Switching mechanisms: Actions that should be put in place once a tipping point is reached to switch from one solution to another. They should be informed by environmental and structural information that is consistently monitored.

This section introduces adaptation pathways. For more information we recommend reading Adaptation pathways for infrastructure operators and policymakers published by the University of Birmingham.

Diagram 2 provides a tool to help develop an adaptation pathway for different asset types.

The central wheel (to be read clockwise) helps to identify the correct process, step by step, to develop an adaptation pathway by understanding the vulnerabilities of assets, developing solutions with all relevant stakeholders, and continually monitoring impacts.

The outside wheel helps to develop options and solutions to populate the pathways. These are meant to be incremental and have short-term, medium-term, and long-term impacts. To help group solutions we have included a series of questions that should be answered at points in the delivery of the pathway.

Lastly, we have indicated some practical examples of solutions through a collection of case studies at the end of this report.

[13] Ferranti, E., Greenham, S. Wood, R. (2021), Adaptation pathways for infrastructure operators and policymakers, Tyndall Centre for Climate Change Research, University of Birmingham

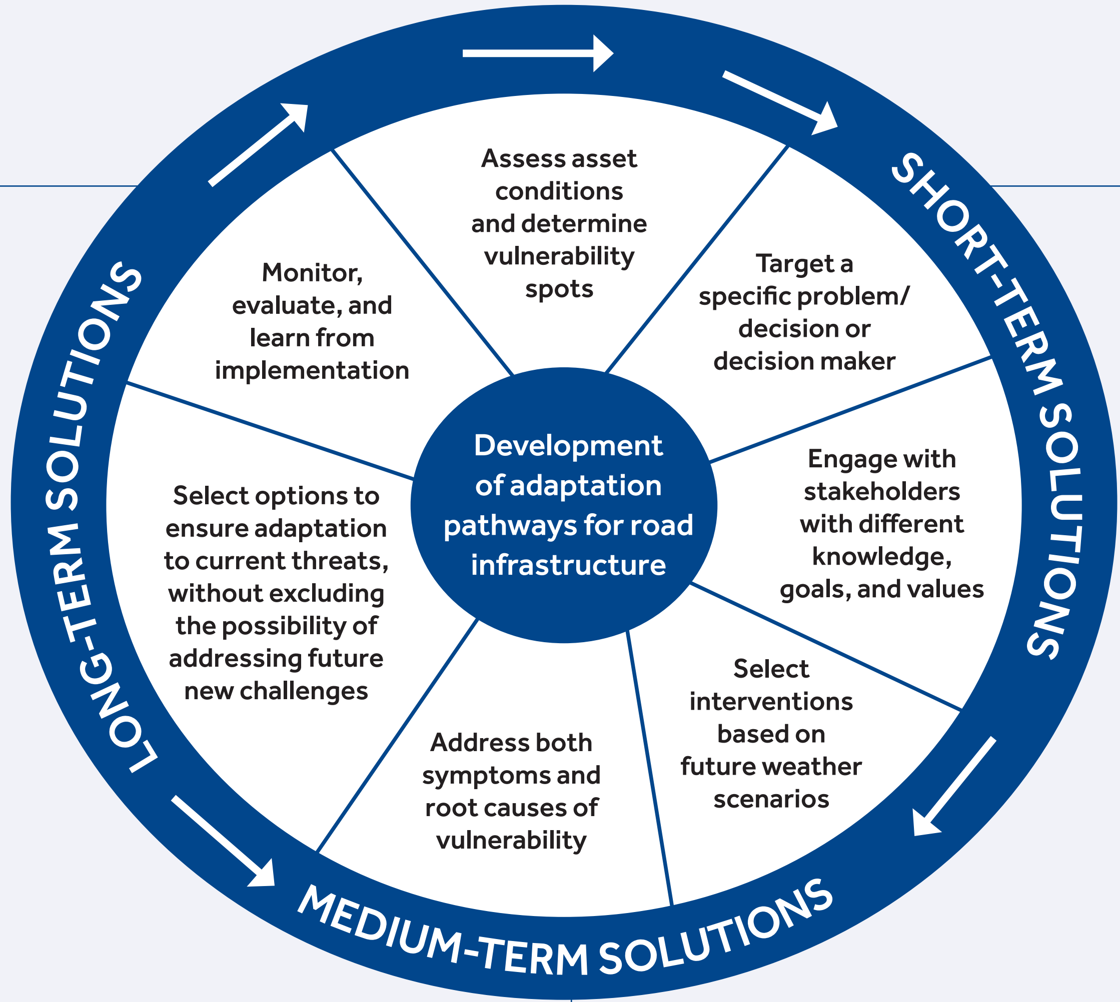
Diagram 2. Tool for adaptation pathway development

LONG-TERM SOLUTIONS

Account for complexities and long-term change, including a potential need for transformation. Measures and solutions are linked to the sustainable development of the area.

QUESTIONS

- Is the infrastructure going to stand increasing pressures from predicted weather?
- How has and will the role of the asset change in the upcoming years considering predicted weather changes, demand, and development patters?
- Has the value of the asset changed for the different stakeholders?
- Are permanent closures and relocation an option?



SHORT-TERM SOLUTIONS

To meet the short-term needs of ensuring that road infrastructure can deliver the service. Targeted interventions to solve specific problems quickly.

QUESTIONS

- What is the biggest issue or priority that needs to be addressed?
- How do different stakeholders value the asset?
- Can measures be ranked according to operability, costs, sustainability?
- What are some no or low regret options?
- What are the tipping points?
- What outcome-focused KPIs should be used for highway maintenance activities in risk areas?
- Do all relevant stakeholders and the general public understand vulnerability, risks, priorities, and decisions?

EXAMPLES

- Improved roadside infrastructure
- Road resurfacing with permeable pavement materials
- Cool roofs and shade green structures
- Permanent road closures
- Retrofitting existing roads and building new and resilient infrastructure
- Elevating or raising roads

MEDIUM-TERM SOLUTIONS

To build adaptation and resilience in the road infrastructure progressively, ensuring that the infrastructure can keep changing, and to learn from past events. Solutions that address both symptoms and root causes of vulnerability.

QUESTIONS

- Does the infrastructure need wider structural interventions?
- Are the tipping points the same? Have they changed?
- How are responsibilities shared among stakeholders? Is there governance in place to ensure value management?
- Has the value of the asset changed for the different stakeholders?
- Do you understand the unintended effects of the options implemented? Do we have a solution?
- Is communication with all relevant stakeholders transparent, clear, and ongoing?
- Are responsibilities clear? Especially when shared?

EXAMPLES

- Emergency floodgates and closure systems
- Sustainable drainage systems
- Heat-reflective paint and coating
- Surface repairs
- Temporary road closures
- Reinforced embankments

Recommendations of PART B

The following recommendations are for supply chain practitioners and highway authorities to rethink their current methods and integrate adaptation and resilience into their operations.

Building resilience is an incremental process. We recommend that supply chain practitioners and highway authorities assess the actions below against cost and deliverability and start implementing what they can presently, with a view to adopting the additional elements later.

Modelling and risk assessment

- **Develop and use models:** Develop models (to forecast for extreme weather events and predict their impacts) coupled with digital twins of the transport system (that consider regional, local, and other geographical factors).
- **Asset inventory:** Improve asset inventory data and its quality for up-to-date asset knowledge to enable proper risk assessment.
- **Wider system costs:** Consider wider system costs, particularly for telecoms and energy distribution systems. The wider impact and costs of an infrastructure failure are often not apparent, and we need to bring these into risk and business models.
- **Undertake training in resilience assessment:** Specific training to assess current infrastructure conditions and risk identification including different extreme weather scenarios.

Strategic planning

- **Proactive and forward-looking resilience and adaptation:** Shift from reactive adaptation to proactive resilience strategies.
- **Resilience and net zero:** Prioritise between resilience and net zero goals, considering how to balance and integrate them effectively. Resilience and adaptation are the treatments for dealing with the impacts from climate change, while net zero policies are the "preventative measures".
- **System thinking:** Promote infrastructure management and planning that accounts for the interdependencies between different systems and the cascading failures from extreme weather to better understand interdependencies and the whole system picture.
- **Stranded assets:** Consider over time whether some assets that are frequently impacted and fail due to climate and weather may need to be abandoned and alternatives sought.

CIHT aims to support the supply chain in achieving the recommendations above in the most time- and cost-efficient way. For this purpose, below are considerations for CIHT that will shape our future work.

Education and communication

- **Training and forums:** Provide consistent language and messages through education and training. Establish forums for sharing lessons and promote cross-sector collaboration. We will support the sector with specific training on resilience assessments through our e-learning platform CIHT Learn.

Case studies

Below is a collection of case studies that showcase the work already happening in the highways sector in relation to:

Physical interventions that can mitigate the impacts of extreme weather events (new materials, construction processes, and design of road infrastructure).

Asset management and maintenance practices that can prevent or reduce the impacts of extreme weather events.

The general lessons learned from the case studies are:

- **A new way of thinking about maintenance.** More frequent extreme weather events are increasing the rate of asset deterioration, although with uncertainty regarding the degree to which changes will impact deterioration. We need to move away from maintenance for roads preservation to looking at strengthening, elevating, and extending infrastructure to reduce the risks associated with future weather conditions. Preventative maintenance will allow the sector to account for the future pressures from possible extreme weather events.
- **Including local future climate projections** that account for changes in climate hazards when evaluating different options and design choices now allows for future improvements to still be possible under different climate change scenarios rather than the present ones. This allows for honest conversations and considerations around the importance of current structures, their potential reuse, and the need for new ones.
- **Implementation (coupled with research) of new materials** that are resilient to extreme weather conditions and therefore will deliver whole-life cost reductions and reduce long-term maintenance costs.
- **In situ recycling techniques** that look at the whole project life cycle and support the delivery of a circular economy (by reusing materials).
- **Green solutions** such as raingardens or trees for shading (using the right tree in the right place) are proven to be an efficient and cost-effective solution for water management and pollution that also delivers economic, environmental, social, and health benefits.[14]

[14] CIHT (2023), Green and blue infrastructure: A transport sector perspective

Table 3. Case studies

Strengthening Apperley Lane Bridge, BAM Nuttall

Structure design and maintenance

Details of the problem and solution

Problem: Bridge pressure from increased water flow

The Leeds Flood Alleviation Scheme involved creating a flood storage reservoir at Calverley along with banking and realigning the River Aire. However, the work at Calverley had the potential to increase the risk of flooding at Apperley Bridge, necessitating the strengthening of the structure to withstand the pressure exerted by the increased flow of water.

Location: Urban

Solution:

The work strengthened, extended, and elevated the Apperley Lane Bridge as part of the Leeds FAS2 scheme. Rotary-bored piles with outer casing were installed across the width of the historic bridge into the bridge abutments. These piles were then advanced through the bridge's road surface and continued through the abutment into the River Aire, reaching the bedrock. The project reduced the flood risk to a 0.5% probability of occurring in any given year, providing a 1-in-200-year level of flood protection for 1,048 homes and 474 businesses in the area.

Added benefits: The Grade II-listed crossing over the River Aire was reinforced as part of a scheme aimed at protecting over 1,500 homes and businesses in Leeds.

Buried structure waterproofing, Fosroc

Materials

Details of the problem and solution

Problem: Chloride erosion of buried structures from cold water

Unprotected buried concrete structures have a shorter life expectancy due to chloride ingress. Traditional bitumen protective coatings are soft and are generally damaged when backfilled against. An epoxy is specified as a protective coating by Transport Infrastructure Ireland (TII). However, this is a time-consuming, highly solvent-based two-part system that can only be applied in temperatures of +10°C. This adds a great deal of time and material expense to every civil project involving buried concrete structures such as bridge abutments, retaining walls, and culverts.

Location: Anywhere

Solution:

Fosroc Brushbond (Black) FLXIII has been formulated to comply with the required EN1504 requirements for the protection of buried concrete structures for transport infrastructure projects, solving the issue of damage due to backfill.

It is primerless and completely solvent-free, so this greatly reduces the environmental impact of solvent-based epoxies.

Being cementitious-based, Brushbond can be applied at temperatures as low as 3°C and cure within 1 hour of application so saves vast amounts of time until backfilling can commence.
Literature and brochures have been created detailing Fosroc's proposal for protecting buried structures, and recent articles have been published on the subject by the Concrete Society.

Added benefits: The use of Brushbond on a number of landmark civil infrastructure projects in Ireland has contributed largely to the reduction of costs and has helped keep projects compliant with schedule requirements.

CIHT

In situ recycling with RoadCem additive, Darlington Fairway and Harris Street

SPL – Stabilised Pavements Ltd

Materials

Details of the problem and solution

Problem: Poor-quality foundation and surface patches with built-up clay

The Fairway and Harris Street in Darlington presented an uneven surface with deep patches and build-up of clay due to various reconstruction works done over five years that resulted in foundation problems. The Darlington authority had carried out repairs with different methods and types of geogrid.

Location: Anywhere

Solution:

SPL was able to introduce a cost-effective solution by using RoadCem, a product of PowerCem Technology, which is a blend of noble and non-noble metals together with synthetic zeolites. Its inclusion within conventional deep in situ recycling modifies the standard cement hydration to allow in situ site soils of any type to be used to replace imported stone as the base element for roads, compounds, and piling and heavy crane platforms. It will remain crack free and waterproof.

Added benefits:

(a circular economy approach)

The use of RoadCem allows recycling to be carried out where it is usually problematic due to poor draining material or bleeding. Where bleeding has occurred in situ, REGEN processes on rural roads have been effective in reducing the layers of the road. REGEN re-engineers these layers by creating a 150mm deep recycled foundation using 2% Cem2 binder then it is double surface dressed using 10mm and 6mm stone.

A27 Worthing and Lancing Improvements, National Highways, Mott MacDonald

Use of weather projections to inform optioneering and preliminary design

Details of the problem and solution

Problem: Include future weather predictions into preliminary design and choice selection

The A27 is the only east to west trunk road south of the M25, linking key coastal communities between Portsmouth and Eastbourne and with the rest of the regional strategic road network (SRN). It serves a population of over 750,000 people and a large number of businesses in the major towns and cities along the route, including Worthing and Lancing. The challenge was to be able to account for future risks related to extreme weather and their impact on the road and include them in option identification, selection, and preliminary design.

This required the establishing of baseline and projections of future climate vulnerabilities. Location: Semi-rural/coastal

Solution:

The climate baseline was formed using Met Office historical regional climate information, and projections were made using Met Office models:

- Met Office, Southern England: climate
- Met Office, UKCP18 Climate Projections

Web searches were used to identify any historic extreme weather events in the vicinity of the scheme. This search identified numerous cases of flooding in recent years along the A27, particularly near Shoreham and Lewes, but none along the section of the A27 where the scheme is situated.

The future baseline was obtained from the UK Climate Change Projections developed by the Met Office Hadley Centre, which include regional climate projection data, for which the scheme is included in the Southern England Region. Under a range of emissions scenarios modelled in the UK Climate Projections (UKCP1843), the region is projected to experience hotter and drier summers, and warmer and wetter winters.

For the assessment period of 60 years from the anticipated scheme opening year (2027), the climate projections data for the 2080s (2080–2099) under Representative Concentration Pathway (RCP) 8.5 scenario available in UKCP18 was selected.

The average summer temperature is estimated to increase by 5.8°C under the central estimate, which represents “as likely as not” probability of change (50th percentile), while the average winter temperature is estimated to increase by 3.6°C (in the 50th percentile or central estimate). For the 90th percentile the average summer temperature is estimated to increase by 8.7°C, and the average winter temperature increase is estimated to be 5.8°C.

The average summer rainfall is estimated to decrease by 41%, whereas the average winter rainfall rate is estimated to increase by 27% (in the 50th percentile or central estimate for both). For the 90th percentile the average summer precipitation is estimated to increase by 7%, and the average winter precipitation is estimated to increase by 75%. For the 10th percentile the average summer precipitation is estimated to decrease by 77%, and the winter precipitation is estimated to decrease by 3%.

From these assessments the vulnerabilities of the scheme to climate change were identified along with their potential effects. These were considered against likelihood and consequences to give a significance statement. Possible high-level mitigation possibilities were also provided. This allows the client to be aware of these before beginning design PCF3.

Added benefits:

The creation of a climate baseline for the area to guide the initial design of the improvements enables options to be selected in a future context that take major variations in rainfall and temperature into account. This makes it possible to choose options that will enable future improvements under conditions other than the current ones to be undertaken and be more cost-effective.

Welsh Government, Mott MacDonald

Development of climate vulnerability assessment for new infrastructure and reuse of existing structures

Details of the problem and solution

Problem: Poor bridge structural conditions

The A494 existing river bridge is in a poor structural condition and deterioration, putting the bridge at risk of failure. The bridge is also not up to modern standards, carrying almost double the traffic it was designed for, with no hard shoulder facility, a narrow footpath, and protective barriers not up to standards.

A preferred option has been identified, which proposes a new river crossing for westbound traffic and the partial reuse of the existing bridge for eastbound traffic.

Disclaimer: At the time of writing this report, the Welsh Government is reviewing the scheme's objectives and proposals to ensure they align with current policy aims and ambitions, following the publication of the government's response to the Roads Review and the four future road building tests in February 2023.

Location: Rural

Solution:

The proposed option has been identified as building a new river crossing for westbound traffic and the partial reuse of the existing bridge for eastbound traffic.

The climate vulnerability assessment used a bespoke methodology adapted from the DMRB LA 114 Climate and the IEMA Guide to Climate Resilience and Adaptation (2020). The methodology includes:

1. Identification of the present-day climate baseline using observed historical data and regional climate summaries from the UK Met Office.

2. Identification of future climate projections (future baseline) using the latest projections from the Met Office's UK Climate Projections 2018 (UKCP18) climate tool.

3. Undertaking a climate change risk assessment (CCRA). This includes:

a. Identification of climate risks during the construction and operational phases of the scheme using the baselines, review of design information, and consultation with relevant engineering designers.
b. Identification of climate resilience measures embedded within the scheme design.
c. Assessment of risk, taking into account the likelihood and consequence of potential impacts. Identification of the significance of risks by combining likelihood and consequence.
d. Identification of additional mitigation to reduce potential significant risks, enhance resilience, and enable adaptability to future changes in climate.

4. Consideration of in-combination climate impacts across other relevant environmental impact assessment (EIA) topics using future baseline conditions.

Welsh Government, Mott MacDonald

Development of climate vulnerability assessment for new infrastructure and reuse of existing structures

(Continued from previous page)

Receptors	Description (to be constructed or modified)
Bridges	• Renewal of existing A494 River Dee bridge to carry eastbound traffic • New bridge crossing of the River Dee for westbound traffic with shared-use path for cyclists and pedestrians • New rail under-bridge (road under rail) at the interface with Chester to Holyhead line
Drainage	• Culvert alongside new westbound carriageway • Drainage pipes • Ditches • Attenuation ponds • Relocation of pumping station and associated electricity substation
Earthworks	• New embankments to be built for road alignment • New retaining structures
Highways features	• Road pavement • Road restraint systems such as safety barriers • Road lighting • Road markings and signs • Other roadside systems • Pedestrians and cycle routes
Landscape and vegetation	• Planting of native species
End users	• Motorised users • Non-motorised users

Added benefits:

Natural and environmental benefits related to SuDS.

CIHT

Deterioration models for geotechnical, assets, National Highways, Mott MacDonald

Assessing asset deterioration rates

Details of the problem and solution

Problem: Deterioration of geotechnical assets due to weather exposure

National Highways is responsible for the management of over 50,000 geotechnical assets (such as retaining walls, embankments, slopes, and constructed subgrades) across England. Geotechnical assets are particularly susceptible to deterioration due to ageing and exposure to adverse and extreme weather conditions, and managing their resilience in a changing climate is a considerable challenge.

Failure of these assets can lead to considerable disruption due to landslides and poses a risk to the safety of road users.

Location: Anywhere

Solution:

Both the inherent deterioration of the geotechnical assets due to ageing and the likely impacts of future climate change need to be considered to support future investment decisions and plan management actions.

Through interviews and discussions with various stakeholders across National Highways, the requirements for modelling the deterioration of geotechnical assets were defined. Strategic-level deterioration models, accounting for the impacts of future climate change, were considered the highest priority.

Using almost 20 years of existing asset condition data within the Geotechnical and Drainage Management Service (GDMS), the National Highways geotechnical asset management system, insights into the current rates of asset deterioration could be understood.

Using this data, Markov chain modelling was undertaken to extrapolate both asset condition and the estimated number of annual failures through to 2080.

Leading academic research into the impacts of climate change on geotechnical asset deterioration was used to inform the creation of climate change uplift factors. These factors helped to define a range of possible deterioration rates and failure frequencies dependent on which climate change scenario occurs.

Climate change is found to increase the rate of deterioration, although with considerable uncertainty regarding the degree to which changes will impact deterioration.

Added benefits:

The inclusion of climate change in these models is a first of its kind for geotechnical assets and will form an important basis for future academic and industry research. The models produced will be a useful tool for informing future decision making by National Highways by:

- Showing demonstrable and measurable deterioration of the geotechnical assets on the strategic road network (SRN), forming part of the justification for future investment in this key asset group.
- Enabling the proactive management of this deterioration by better informing decision making on engineering interventions or mitigations.
- Providing better understanding of how key asset characteristics such as type or geology impact upon deterioration rates, enabling better targeted investments.
- Providing a clear narrative for the likely impacts of climate change on geotechnical assets and forming a useful input into future climate change risk assessments undertaken by National Highways.

Although decision support tools have not yet been developed for the geotechnical assets managed by National Highways, the deterioration models produced in this task will form a key input into any future tool.

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Eco-Thaw Premium liquid de-icer solution, Brine Solutions Ltd, and Transport Scotland

Snow and icing of road surfaces

Details of the problem and solution

Problem: Use of pre-existing fleet of pre-wet spreaders and normal treatments not strong enough against first snowfall

Motorway closures in each winter season during snow events has been a difficult situation to manage due to the motorway terrain, initial normal treatments not being strong enough to combat first snowfall, and traffic build-up in the affected areas preventing retreatment, leading to further snow build-up and closing of the route.

Location: Anywhere

Solution:

Brine Solutions Ltd developed a liquid de-icer solution, Eco-Thaw Premium, to address the weakness in current snow treatments (pre-wet or dry applications). The product is used as a replacement for the brine element in the pre-wet application.

Eco-Thaw has a freezing point around −26°C, it is active immediately, and can cater for a 2- to 3-inch snow event. It has an active element that encapsulates the dry salt portion of the treatment, activating the salt and bonding more product to the road surface, reducing loss to traffic, and maintaining a strong road surface treatment during snow and ice events.

The product is pre-made and does not require any mixing on site or modifications to spreaders.

After three years of winter trials on the M6/74, M8, and M77 in locations that were identified as high risk and that have had closures in the previous winters, Eco-Thaw was chosen and used as an innovative solution to enhance pre-wet applications during snow events due to its unique blend and performance abilities.

Feedback has been positive from all areas: sections where the product has been used, which had closures each year for over 20 years, have remained open and clear.

Added benefits:

- Reduced application frequency.
- Reduction in treatment runs, giving a benefit in less salt applied to maintain effective road condition.
- Cost savings achieved in less runs and less salt applied.
- Network remained open through snow events with a clear and safe road surface condition.

Trees as stormwater attenuation and treatment pits

Keighley, West Yorkshire and Sauchiehall Street, Glasgow

Keighley, West Yorkshire

Following several consultations, Bradford Metropolitan Council decided to make some alterations to the road network in and around the town centre to alleviate the traffic gridlock that was becoming a feature there.

Due to the combined sewer capacity issues, and to maximise the value of the new tree planting, it was decided to use the tree pits as stormwater attenuation and treatment pits, taking water from the carriageway, passing it through a stone layer on the top of the tree pit, and then filtering it down through the specialist soil for the root growth.

The water then transferred through a clean stone layer to infiltrate back into groundwater. This method of conveyance gives an acceptable level of pollutant removal and slows the water down so that the discharged stormwater does not contaminate the local aquifer.

Recent soil testing by Manchester Metropolitan University showed that the pollutants were largely held in the silts within the top 25mm of soil, and the rest mainly within the top 250mm. These findings show that a healthy soil with trees growing in it offers pollutant trapping and bio-remediation services, even without much maintenance.

We also note that the trees that have the largest share of the run-off have exhibited the fastest canopy growth, indicating that there is a direct correlation between water ingress and tree vitality.

Sauchiehall Street

Central to the Green Avenues plan was to increase canopy cover in urban areas. Sauchiehall Street was the pilot scheme to showcase how green infrastructure can be used to change human behaviour by challenging the dominance of vehicles in the public realm. In this scheme, 28 specimen trees have been planted in full GreenBlue Urban ArborSystems, providing a strong visual segregation between vehicles and pedestrians/cyclists. The tree pits are linked together, providing maximum rooting space in uncompacted aerated soil, giving the trees the best opportunity of attaining species potential. As well as the aesthetic attractiveness (encouraging a pavement café culture atmosphere) these trees also provide a measure of pollution absorbance and help cope with stormwater management by treating water run-off from the paving areas through the tree pit soil. An additional benefit is an increase in sustainable travel, with a rise in cycling of approximately 80% reported.

SuDS and raingardens

Greener Grangetown

Greener Grangetown in Cardiff is a very interesting example of the successful retro installation of SuDS features into an existing urban streetscape. The work was commissioned by City of Cardiff Council, Dŵr Cymru Welsh Water, and Natural Resources Wales and led by Arup. Arup's water engineers and placemaking team designed solutions that integrated SuDS with public realm improvements. As well as slowing the flow, cleaning water naturally, and reducing the financial and carbon costs of pumping wastewater, a key goal was to ensure that Greener Grangetown delivered a wide range of economic, social, and environmental benefits.

Southend, Essex

To tackle climate change, Southend Borough Council became a partner of the EU Interreg 2 Seas programme Cool Towns.

Funding was received to support the enhancement of the town centre, reduce the risk of flooding, and mitigate against the effects of heat stress through evapotranspiration, measurably cooling the air.

London Road, a main public access point to Southend High Street, was highlighted as the area of implementation. Little to no shading and taxis running in the taxi rank contributed to increased temperatures in the area.

Through the town improvement project, the taxi rank was moved and there was an enhanced footway, new block paving, street furniture, green cycle parking shed, and a row of trees with sustainable drainage capabilities.

The scope was updated to install fewer but substantially larger trees that would provide greater initial impact and the shading required by the Cool Towns initiative to tackle heat stress.

Resilience calculation design tool for planned maintenance of linear drainage systems, ACO Technologies plc

Maintenance of drainage systems

Details of the problem and solution

Problem: Overlooked maintenance of drainage systems

The importance of proper maintenance of highway drainage infrastructure is something that cannot be overstated and is frequently overlooked. Funding for this is often very short sighted and when budgets are tight, one of the first things to go as a "cost saving" exercise is to reduce maintenance of the drainage systems.

As well as the direct and immediate impacts that flooding causes on the road network, poor drainage maintenance leads to more standing water on the highway, exacerbating the decline of the structural integrity of the carriageways, footways, and other structures.

Location: Anywhere

Solution:

ACO has incorporated a resilience design function into its online QuAD hydraulic design software for linear drainage channels and combined kerb drainage in order to propose site-specific resilience and maintenance regimes at the design stage.

There is guidance within DMRB (CD 523 section 2.1) in terms of silt build-up, which suggests urban roads generate more sediment than rural roads, in the order of 200g/m2 per year, of which around 90g/m2 per year is retained in gully pots.

Using guidance such as this, typical sedimentation values and densities can be predicted for certain types of sites (e.g. rural roads, urban roads, commercial and industrial centres). Linear drainage systems can be designed in the QuAD software for site-specific locations or rainfall (e.g. 1 in 5 year, 1 in 30 year, 1 in 100 year storm return periods) plus appropriate allowances for climate change. Based on these specific design criteria the appropriate resilience of the systems can then be reviewed and proposed maintenance schedules drawn up.

Added benefits:

Designing for effective and planned maintenance of drainage systems helps to prevent flooding and standing water on the highways network. This has multiple benefits including:

- Reduces deterioration of the structural fabric of the highways network.
- Reduces untreated pollution entering the surface water systems and the natural environment.
- Social benefits in terms of less disruption on the network.
- Cost savings in lost time, unplanned reactive works, and traffic management.

Flood modelling for bridge improvements, A487 New Dyfi Bridge

Modelling and planning – Commended in the 2024 CIHT Infrastructure Awards

Details of the problem and solution

Problem: The bridge needed maintenance and improvements, but works needed to be carried out in a floodplain

Dyfi Bridge is on a new 1.2km section of the A487, just north of Machynlleth. It crosses the Afon Dyfi floodplain and river on an elevated viaduct. The scheme was a technical challenge and innovations were required to overcome these challenges.

The scheme improves the resilience of a strategic route in Wales to the long-term impacts of climate change, providing vital connectivity to healthcare, education, employment, and leisure. It provides opportunities for economic growth by improving the connectivity and reliability of the road network, and improving the social and environmental conditions within the Machynlleth area.

Location: Anywhere

Solution:

The scheme involved crossing a flood plain, necessitating a design that would not significantly impact existing flooding conditions. An iterative design process was employed to ensure compliance with relevant guidance and legislation. The primary challenge was managing the impact on river flooding and minimising future flood level increases. Initial flood modelling showed unacceptable flood level increases, leading to the exploration of various options. The solution was a longer viaduct, which reduced flood level impacts.

Throughout the design, the team collaborated with Natural Resources Wales (NRW) to agree on the assessment of the hydraulic regime and the criteria for acceptable results. The final design included a 750m viaduct with 20 spans and a 74m clear span over the river. Weathering steel was chosen for its low corrosion rate and long design life. Additional flood mitigation measures included a flood bund to protect the Eco Park, two pumping stations to prevent highway flooding, and the closure of the original Pont-ar-Ddyfi to traffic. The project also incorporated parking, traffic calming, and a non-motorised user crossing on the A493. The scheme's KPIs were aligned with the Welsh Government Performance Monitoring Regime.

Added benefits:

The scheme ensures continued access for vehicular traffic to essential services like education, work, and healthcare. It also provides active travel opportunities through a 2.5-metre-wide shared-use active travel link to promote healthier lifestyles and enhance the wellbeing and resilience of local communities.

Although the initial cost of weathering steel is more expensive, the corrosion rate is so low that bridges fabricated from unpainted weathering steel can achieve a 120-year design life with only nominal maintenance. Hence, a well-detailed weathering steel bridge in an appropriate environment provides an attractive, very low maintenance, economical solution.

Mapping climate risk and vulnerability with publicly available data, University of Birmingham

Modelling – Commended in the 2024 CIHT Research Awards

A climate risk and vulnerability assessment (CRVA) map is a tool to communicate climate risk and identify potential impacts on society. CRVA maps help prioritise, target, and plan adaptation investments to the needs of a place.

A CRVA map requires several layers of data that would contribute to climate risk. The data parameters could include: physical (e.g. urban form, flood zones); environmental (e.g. temperature, air quality); and social (e.g. health, social deprivation).

Each data layer is standardised in terms of both spatial scale and values. Then they can be easily combined into one single layer that represents the total climate risk across the map. It is important to note that this CRVA map is not an absolute assessment of climate risk and vulnerability, but only relative within the boundary of the area being assessed, which in this case is the Birmingham city boundary. This means that it cannot be directly compared with another city or region.

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CIHT

About CIHT

CIHT provides strategic leadership and support to help our members develop, deliver, and maintain sustainable solutions for highways, transport infrastructure, and services that:

- **Address the challenges of climate change**
- **Support the economy**
- **Help address societal inequalities**
- **Reduce environmental degradation**
- **Respond to a changing world**

We bring members together to share, learn, and feel confident about addressing these challenges through the application of good practice, by embracing innovation and by acting with integrity. It is through this and the values that CIHT can demonstrate and deliver on thought leadership and shaping the highways and transportation sector for the public benefit.

Whether you are a student, apprentice, work in the private or public sectors or are a company director, CIHT has a place for you and a commitment to fulfilling your professional development needs throughout your career.

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