MUSEUM INTERCHANGE

ARUP HITACHI GOWLING WLG

Transport resilience in a changing climate

The case for investment

A report by Arup, published as part of London Transport Museum's Interchange programme

About Interchange

Established in 2009, Interchange is London Transport Museum's thought leadership programme.

We bring together senior level experts from different sectors to discuss key issues facing transport and infrastructure sectors and beyond. Through an annual series of events and workshops, we curate guest lists featuring key stakeholders and thought leaders – including Transport for London, AI and tech specialists, manufacturers, transport operators, local and national government representatives, law firms, consultancies, and campaigners – to foster the exchange of knowledge and creative thinking.

Although the Museum is based in the heart of London, we discuss the national and international challenges and impacts and invite guests from across the UK and further afield to share their experiences and case studies. Throughout this series on climate resilience, we have collaborated with our Interchange sponsors, Hitachi Rail and Gowling WLG and our content partner, Arup to co-curate a series of engaging events leading to this thought provoking report that captures participants' ideas and insights.

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Elizabeth McKay
Director and CEO,
London Transport Museum

London Transport Museum tells the story of a city shaped by innovation and problem-solving.

Our collection spans over 200 years, showing how Londoners have adapted transport to meet changing needs – from developing the world's first underground railway in 1863 to solve urban congestion, to today's smart ticketing systems tackling long queues and delays.

Now, climate change presents a new and urgent challenge. From buckling rails in extreme heat to flooded stations, our transport systems must become more resilient. This year's Interchange report tackles these issues head-on, exploring how we can build transport networks that are both sustainable and equipped to withstand climate hazards.

At London Transport Museum, we believe in the power of learning to drive change. Programmes like Enjoyment to Employment empower young people to solve real-world problems, and climate resilience is central to our mission. Interchange, our thought-leadership initiative, convenes experts to spark ideas and move the sector forward.

In partnership with global consultancy Arup, this year's report identifies barriers to adaptation and highlights actionable solutions. From London's sustainable drainage systems to nature-based solutions mapping tools, diverse case studies show how collaboration and innovation can transform vulnerability into strength. Crucially, we must back this work with data and storytelling – to quantify the value of resilience and shift public perception.

We thank Arup, Gowling WLG and Hitachi Rail for their vital contributions. Whether you are an industry professional, policymaker or government representative, we hope this report inspires you to reimagine transport as a force for enduring resilience.

Arup

Foreword

John Fagan
Transport Leader, UK, India, Middle East and Africa region

Even if the world's transport networks are increasingly feeling the effects of climate change, adapting our systems to ensure their resilience is a choice. The alternative is a wait-and-see approach, which leads to missed opportunities, damage and downtime.

The cost of inaction is real, but organisations often struggle to invest in adaptation as they see the need for trade-offs. The question is when and how to incur these costs, at an unknown future date through losses and disruption, or sooner through targeted investment at the right time.

While localised efforts aimed at navigating climate-related challenges exist, there are still barriers preventing the investment in climate resilience.

However, overcoming these challenges is not possible without a holistic approach that integrates resilience into every stage of the lifecycle – from asset planning and design to maintenance.

Ensuring resilience is not an afterthought, but a guiding principle, that will enable transport organisations to invest in long-term actions rather than short-term fixes.

Resilience goes beyond physical interventions to our streets, roads, railways, airports, and ports. It is about people and connectivity. A resilient transport system allows communities to access critical services during flood or extreme heat events, and networks to recover rapidly from disruption. By looking at the bigger picture and thinking ahead, the industry can design new transport networks or maintain existing ones that are not just functional today, but also tomorrow.

As our approach to transport evolves, so too should our behaviours and expectations about the transport network.Whether you are an asset owner, an operator or a passenger, a shift in mindset is needed to embed resilience at the core. We are committed to supporting this transition, shaping transport systems that are future-ready and can withstand the pressures of climate change for years to come.

Executive summary

The detrimental effects of climate change in communities and the infrastructure that sustains them cannot be denied.

Already behind the target to limit warming to 1.5°C above pre-industrial levels, countries around the world are facing flooding, heatwaves, storms and other extreme events. As little or not enough action has been taken, the effects of climate change will become more frequent and severe, increasing strain on critical infrastructure such as the transport network.

As a key enabler of economic growth, access to education, healthcare and opportunity, transport underpins the functioning of society. When transport fails, lives are disrupted, local economies are hit, and inequalities are deepened.

Given the industry's acute vulnerability to climate risks, the high costs of inaction and the strong economic case for investment in adaptation and mitigation measures should be a priority. However, it remains underinvested due to budget constraints and short-term assessments of return on investment.

At the heart of the Interchange series was a deliberate convening approach: bringing together a diverse group of leaders from across the transport sector, including public and private stakeholders, operators, businesses and technical experts, to reflect, challenge assumptions, and think beyond institutional boundaries.

Informed by these insights and wider industry expertise, this report explores the challenge of building climate resilience, identifying five critical opportunities to accelerate progress and practical solutions to act on them.


Finsbury Park Station
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To future-proof transport networks and avoid escalating costs to society, the economy and the environment, transport organisations must:

Establish common goals

The transport sector needs a clear, shared goal that goes beyond individual objectives. Major transport bodies such as Network Rail or National Highways should collaborate to agree a SMART (Specific, Measurable, Achievable, Relevant and Time-bound) target. This would create consistent, actionable standards across infrastructure while setting an ambitious but achievable direction.

Inform decisions through data and innovation

Governments should establish clear resilience standards, requiring bottom-up data collection that attributes costs to climate hazards. Innovative tools and artificial intelligence can be harnessed to enhance and standardise data collection and decision-making, while existing data must inform urgent action and should be shared across organisations.

Build cross sector collaboration

Given the complexity and interconnectedness of the transport system, collaboration is a must to reducing the risk of cascade failures. Together with leadership from Government, third-party mediators and professional membership organisations can become spaces for coordination and sharing data and tools, moving beyond reliance on ad-hoc relationships.

Adopt a resilience mindset

Climate resilience must be perceived as an economic opportunity rather than an investment risk, showing its tangible benefits. Transport bodies should engage communities by showcasing relevant success stories that demonstrate low risk, high impact methods. Then, they can expand by building a library of case studies that highlight the real-world value of resilient infrastructure.

Implement resource and finance effectively

Innovative funding models, including public-private partnerships, and other mechanisms such as green and resilience bonds, should be leveraged to unlock funding and skills, proactively embed resilience and enable faster and more targeted adaptation.

If implemented, these measures should support the creation of a resilient transport network across the UK and beyond, so that future populations are able to thrive in a changing climate.








01

Climate resilient transport

The transport system acts as the veins, arteries and capillaries of a social system, with all modes working in concert to move goods and people to sustain a good quality of life.

Defining transport resilience through social value rather than mode-based business outcomes provides a means to acknowledge the shared nature of climate risk and to collaborate effectively in addressing it.

A budgetary gap already exists for maintaining the UK's ageing infrastructure, but the challenge is exacerbated by the growing gap between adaptation and the rate of climate change.[1] Repairing damage and recovery is a costly business, financially, socially and environmentally.

Repairs have a carbon footprint and financial loss that we wish to avoid and usually exceed the costs of pre-emptive adaptation. However beneficial it may seem to invest proactively in adaptation, the great challenge is the current lack of funding to upgrade existing infrastructure today for benefits in the longer-term future.

A climate-resilient transport network is not a luxury, it is a must for maintaining economic competitiveness, social equity and safety. It is a system that, over long-term and short-term extreme weather events, manages to maintain critical logistics, so that disruptions to local economic activity, community safety and wellbeing are well mitigated, short-lived and recoverable.

The question is not whether we can afford to invest in resilience, but whether we can afford not to.

Cost and disruption – evidence of the climate's impact on transport

Current climate projections show that we are already close to the Paris Agreement target of 1.5°C average global temperature increase and are on track to reach 2.7°C.[2]

In the UK, the Met Office UK Climate Projections 2018 models find that the country will experience hotter winters and summers (up to 4°C and 5°C respectively), and the latest will become more frequent (rising from 12.5-25% to 50-60% by mid-century). In addition, hot spells (two or more consecutive days over 30°C) are estimated to occur over 20 times more frequently in the future, rising from 0.2 to 4.1 occurrences per year by 2070. While temperatures are expected to increase, the evolution of precipitation will be variable by season and region. By 2070, summer precipitation is expected to reduce up to 45% and winter precipitation to increase by 39%. The convective season will extend from the summer, bringing increased hourly rainfall intensities into the autumn. Furthermore, sea level is set to rise between 0.5-1.0 metres in areas like London and Edinburgh by 2100.[3] The Climate Change Committee has warned that efforts to address these risks are 'too slow, have stalled, or are heading in the wrong direction'.[4]

These projections together with the extreme weather events in the past few years have made even more evident the impacts of climate change in our transport networks. Storm Bert, taking place between 21st and 26th November 2024, is likely to have generated £250-350 million insured losses alone.[5] However, there is a lack of a reliable single value that includes all infrastructure and uninsured property and business losses. In the transport sector, 400 flights were cancelled and roads and rail services experienced severe disruption.[6] Services into London Paddington, with 90,000 passengers per day, were severely affected alongside the West Coast Mainline, which serves on average 200,000 passengers per day.[7] Communities and businesses suffered the impacts for the weeks following, as landslips and fallen trees were addressed.

It was not just the economy that was hit, the human impacts were pressing. A total of 350,000 homes lost power and more than 300 schools were shut or partially closed across the Scottish Highlands and in Devon and Cornwall due to the snow.[8] Many people were forced to work from home without reliable power or internet, while others were unable to travel to work at all, cutting off access to income and essential services.

£350m
In insured losses linked to Storm Bert flooding, UK, 2024

400
Flights cancelled due to Storm Bert, UK, 2024

20x
More frequent hot spells by 2070

£10m

Losses due to decreased passenger numbers during the July 2022 heatwave

On 19th July 2022, the temperature reached 40.3°C, shattering the previous UK record of 38.7°C set in 2019. This heatwave was a 1-in-1,000-year event and was made ten times more likely due to climate change.[9]

During this period, around 15,000 homes went without power as equipment overheated while vehicles with electric motors were subject to heat-related problems.[10]

Network Rail reported passenger numbers down by 40% compared to the previous week, causing losses of approximately £10 million and extreme temperatures also led to roads melting, and airports closed due to surfacing issues on runways.[11]

All heatwaves in the UK across 2022 were linked to 2,985 excess deaths in England, with the resulting economic impact estimated at £260-300 million.[12] This is in addition to the significant costs associated with lost productivity, healthcare costs and infrastructure damage.

Whether it is rain, wind, heat or snow, climate events are already having a significant impact on the transport network (Table 1). With exposure to these risks becoming more frequent and severe, these historic costs are nothing compared to the potential losses the transport industry might face in the years to come if no action is taken.

Table 1 - Main climate impacts by transport mode [13]

Hazards	Land transport [14]	Aviation	Maritime transport [15]
Extreme heat	– Deterioration of materials: e.g. asphalt rutting, rail buckling, Intelligent Transport Systems overheating – Thermal expansion of bridges and joints – Damage to machinery and engines – Wildfire and smoke risk – Reduced construction work hours	– Longer airport runway requirements	– Less inland navigation at low water levels – Obstacles to inter-oceanic passages such as drought – Thawing of Arctic waters
Sea level rise	– Inundation of roads and rail lines – Flooding of underground tunnels – Erosion of road and bridge supports	– Inundation of runways	– Higher tide and storm surges and flooding of ports – Reduced clearance under bridges
Soil humidity	– Subsidence of substrata – Structural instability for bridges – Increased landslide risk	– Subsidence of substrata	– Subsidence of substrata
Extreme storms	– Damage to roads, railway superstructure, lighting, power and communications – Traffic disruption from felled trees storm debris	– Damage to airport superstructure, lighting, power and communications – Temporary closure of airports	– Damage to port superstructure, lighting, power and communications – Temporary closure of ports – Damages to ships, loss of cargo and loss of life at sea – Pollution and dangerous goods risk – Storm debris damages

Current barriers to investment in climate resilience

Transport operators, infrastructure owners and local authorities bear the financial burden of resilience measures, while the wider economy and society benefit from reduced disruption and increased stability.

However, demonstrating a clear return on investment is difficult. Climate impacts are inherently uncertain in both timing and severity, and the most extreme hazards are often projected far into the future, beyond typical business, planning and political horizons. This misalignment with the short-term risks that operators routinely manage, combined with uncertainty in climate models, makes it harder to justify upfront spending. Additionally, weak regulatory and financial incentives alongside a lack of appraisal methods to quantify the benefits of resilience mean it is rarely embedded into transport planning at the level and time required.

Meaningful action requires bold leadership, innovative funding and stronger policies backed by lasting government standards and legislation. This report explores the following key barriers that must be overcome to unlock future resilience:

- Lack of common goals: Different stakeholders, from government bodies to private operators, often have competing priorities against differing standards. This leads to fragmented efforts rather than a coordinated resilience strategy.
- Limited collaboration: Effective resilience planning requires cross-sector cooperation, but siloed decision-making limits integrated solutions.
- Resource and funding constraints: Many transport agencies lack the skills, workforce and technical expertise, as well as financial resources, to develop and implement resilience strategies effectively.
- Data gaps: High-quality, real-time climate and transport data is not being collected and not attributed to weather conditions. Additionally, many organisations do not have the necessary analytics capabilities.
- Outdated mindset: Future resilience is still taken for granted and seen as a secondary consideration in transport project planning rather than a core priority. A shift in mindset is needed to view it as an essential component of long-term planning.

02

Benefits of building resilience

Resilience is not just a solution to a climate issue, it is a powerful economic opportunity.

In a time when economic growth is a top priority, understanding the link between resilient transport and development is more important than ever. When assessing investment in adaptation, capturing the full value of resilience (financial, economic and human) is essential.

Alongside the economic opportunity, resilience presents a unique social and environmental opportunity to tackle this challenge with interventions that will also improve quality of life. Climate resilience can make our infrastructure greener, fairer and better integrated with the communities they serve. Initiatives such as encouraging active travel and using nature-based solutions are examples where transport resilience is improved through mitigating the negative impacts of weather hazards, while having knock-on benefits on health, wellbeing and biodiversity.

Investing in transport resilience directly supports the UN Sustainable Development Goals (SDGs) by building systems that are more equitable, sustainable and future-proof in the face of climate change. It promotes fairer growth (SDG 8), supports greener, more connected infrastructure (SDG 9) and reduces inequality by ensuring access to jobs, services and opportunities (SDG 10). It also helps cities become more inclusive and resilient (SDG 11) and strengthens climate action by reducing exposure to climate risks (SDG 13), all underpinned by long-term cross-sector collaboration (SDG 17).

Building transport resilience can unlock wider benefits that align with UN Sustainable Development Goals, and support net zero targets.

Image: ©Transport for London

Unlocking the wider value of investing in resilience

The triple dividend of resilience framework is an approach designed to capture the full value of investment in resilience.

The framework goes beyond just considering the additional value of protecting assets and infrastructure, and recognises the wider development and social benefits that investment towards a resilient transport system can bring, identifying three types of benefits (Figure 1):

– Avoided losses: Resilience reduces costly damage and disruption from climate events, cutting repair costs, keeping insurance premiums down and services running.
– Economic and development benefits: Resilient infrastructure supports growth by creating jobs, attracting long-term investment by providing reliable connectivity, unlocking agglomeration benefits.
– Social and environmental co-benefits: Nature-positive, low-carbon and community focused measures can deliver wider outcomes to the environment and society, even without a climate event.

While the first dividend depends on a climate event occurring, the second and third deliver value regardless, making a strong case for investment and generating high benefit-cost ratios (BCRs) even in the absence of extreme weather. A BCR compares the benefits of a project to its costs, providing a key metric used by funders and government to determine value for money. The higher the BCR, the more likely a scheme is to be prioritised and approved.

Figure 1: The triple dividend of resilience


Image: ©Transport for London

Protecting against the cascading effect of transport damage and disruption

Transport is a critical enabler, when it fails other systems follow. As such, it is especially vulnerable to cascade failures, where disruption in one part of the network triggers a knock-on effect elsewhere.

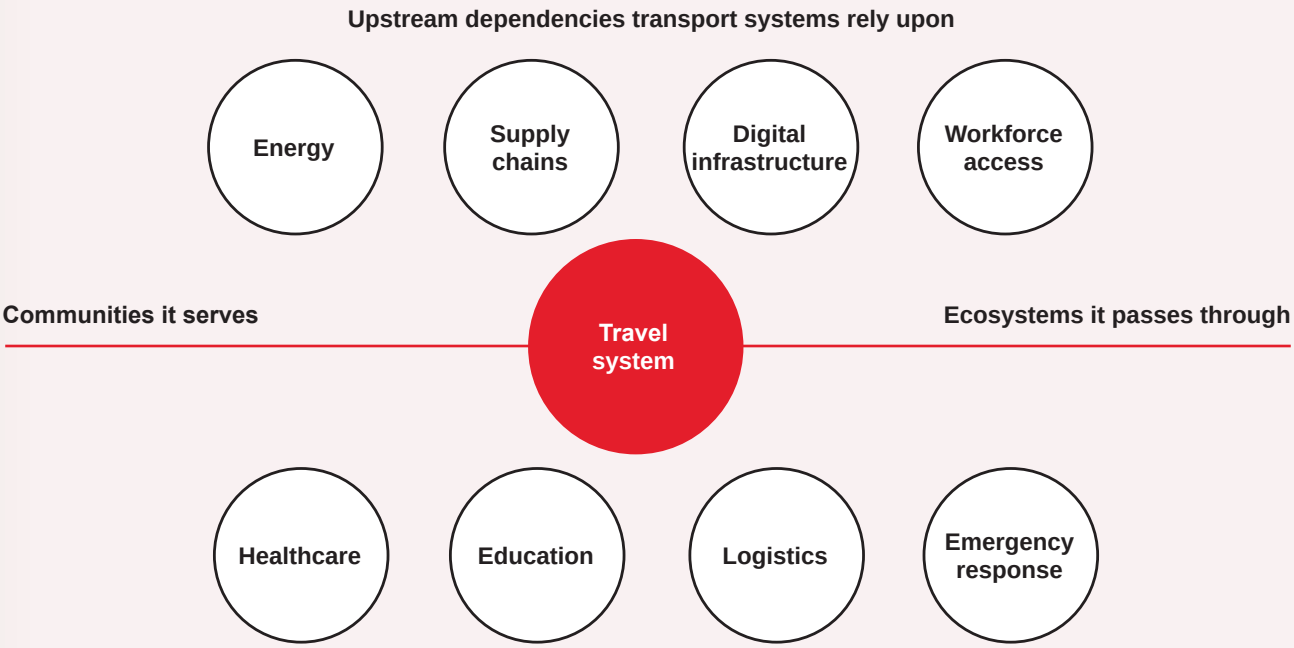
For example, a flood event or buckled tracks from heat could trigger a chain of events across the entire transport ecosystem and beyond, disrupting supply chains and cutting off access to jobs, education and healthcare. This was starkly illustrated in the third Climate Change Risk Assessment, which found that for every £1 of direct loss in the rail sector due to a climate event, the wider economic loss amounted to almost double.[16]

A real-world example of this is when the coastal railway at Dawlish was swept away in 2014, severing Cornwall from the rest of the network. It cost the local economy £1.2 billion over eight weeks, on top of the £5 million required to repair the railway.[17]

Resilience depends on the whole transport system functioning, not just individual assets in isolation. A transport network is made up of interconnected elements (physical infrastructure, operations, people and systems), but it also sits within a wider network of social, environmental and economic contexts. Its resilience is shaped as much by the communities it serves and the ecosystems it passes through as by its physical condition. Understanding how these parts interact is essential.

A systems view helps identify hidden vulnerabilities, manage cascading risks and build a transport system that supports broader resilience across society. This means considering both upstream and downstream dependencies. Transport relies on upstream systems such as energy, digital infrastructure, supply chains and workforce access. In turn, it enables critical downstream services like healthcare, education, logistics and emergency response (Figure 2). Disruption in any one part can ripple across the system, hence taking a whole-systems perspective helps target resilience investment where it can prevent cascade failure and unlock wider benefits.

Figure 2: Upstream and downstream dependencies



Shaping a transport system that supports broader resilience across society

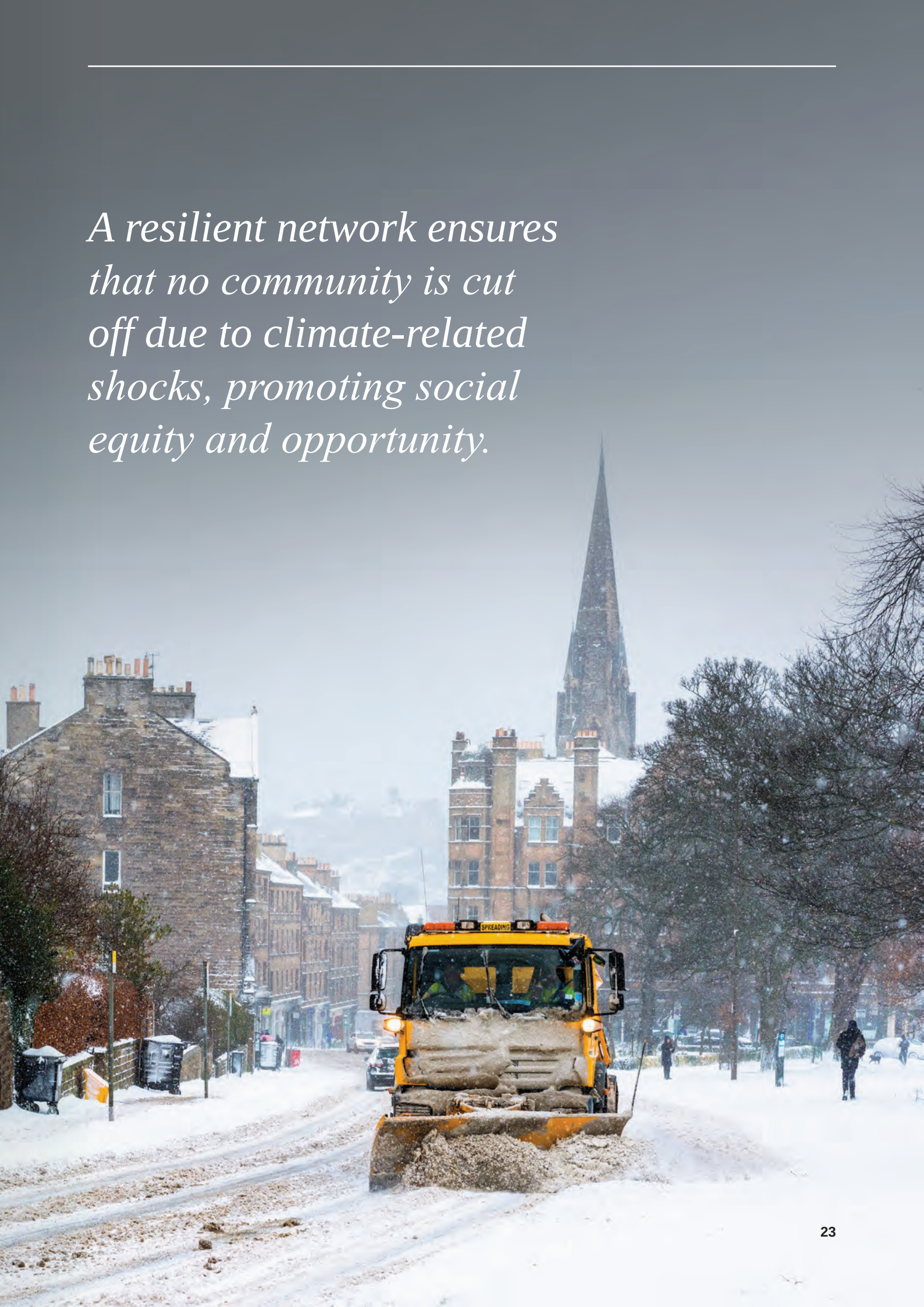
While financial considerations are often the initial focus, it is the human impacts that can be most powerful.

A resilient world is one where people can get to work, access healthcare, food and education or meet their family and friends reliably and safely. It means fewer cancelled trains stranding commuters, fewer flooded roads cutting off communities and protected everyday connections. In this place, transport is also greener, promoting fresher and cleaner air.

However, transport disruption does not affect everyone equally. For groups facing traditional barriers to access, our network is vital in maintaining connections to essential services, employment and recreation opportunities. According to the Department for Transport National Travel Survey published in 2023, households in the lowest income quintile made the most public transport trips and the fewest private transport trips during 2023.[18]

This is reinforced through Transport for London statistics, which show that 61% of all Londoners use the bus at least once a week, compared to 74% in the lowest income bracket (>£5,000).[19] These results underline the larger impact on this group, demonstrating how the lack of resilience exacerbates social inequality.

A resilient network ensures that no community is cut off due to climate-related shocks, promoting social equity and opportunity.



03

Achieving climate resilience

The following sections explore solutions to the current challenges to investing in resilience.

- **Establish common goals**
- **Build cross sector collaboration**
- **Implement resource and finance effectively**
- **Inform decisions through data and innovation**
- **Adopt a resilience mindset**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Achieving climate resilience

Establish common goals

Image: ©Transport for London

Overview

Common goals can shape the direction for investment and forward planning, bringing together organisations to strive towards the same objectives.

Clear goals lead to standards being put into place to achieve them. Without the former, the latter are nowhere near as effective. As of 2025, there is no one goal or set of standards for resilience. Without common guidance, there is no ability for individual firms to work towards similar goals. Even if climate resilience aims should be specific to the context, such as the criticality of the infrastructure, a unified framework can help bridge the gap between individual standards and practices.

A set of consistent aims would facilitate communication and collaboration across different transport modes and locations. A well-known example of this is the net zero carbon emissions target, which proves that establishing objectives can provide the foundations to build these frameworks and foster collaboration. By implementing specific goals at national, regional and organisational levels, it becomes much easier for organisations to understand and implement the actions needed to build resilience at every stage of the project lifecycle.[20] Having a defined aim enables stakeholders to collaborate more effectively and develop long-term strategies, addressing the complexities of integrated governance and systems thinking necessary for resilience.

Why it matters

The lack of cross-sectoral communication, unique contexts within which each organisation must balance their resilience goals and the lack of existing common frameworks are key blockers within this space. Climate resilience is not a problem that can be solved by one organisation alone, requiring collaboration across sectors, industries and geographies. Even within individual organisations, varying levels of resource and importance is assigned to climate resilience. To overcome poor communication and reinforce the value of resilience to key stakeholders, it is essential to establish common goals that link together these disparate actors.

Resilience is unique to the context within which organisations operate, and therefore establishing common resilience goals can be highly challenging. Resilience itself is a term still being understood in different ways, and a climate resilient future will look different for organisations operating in different spaces.

For this reason, collective objectives need to be more complex than simply setting one cross-industry target such as net zero. Organisations must adapt their climate resilience goals to not only fit into a wider sectoral structure but also meet the unique challenges of their specific industry, area of expertise, and prevalent weather conditions (heat, cold, rain and drought).

What to do

Cross-industry standards:

Setting mandatory standards can be an alternative pathway to resilience. They can also help to develop an understanding of this concept and the methods to make it happen across organisations. By establishing key metrics and focusing on feasible and realistic outputs, the industry can create a clearer framework to achieve consistency. Standards being set for reporting, spend, milestones and other measures would build a more complete picture of what resilience should be.

Agreement on specific resilience goals:

Having a guiding north star for resilience cross-industry will give all organisations something to strive towards. While unique contexts require their own specific goals, having an idea of 'what good looks like' is important for keeping organisations moving forwards towards more resilient futures. The UN Sustainable Development Goals are a good example of specific and context appropriate targets.

Joined up governance:

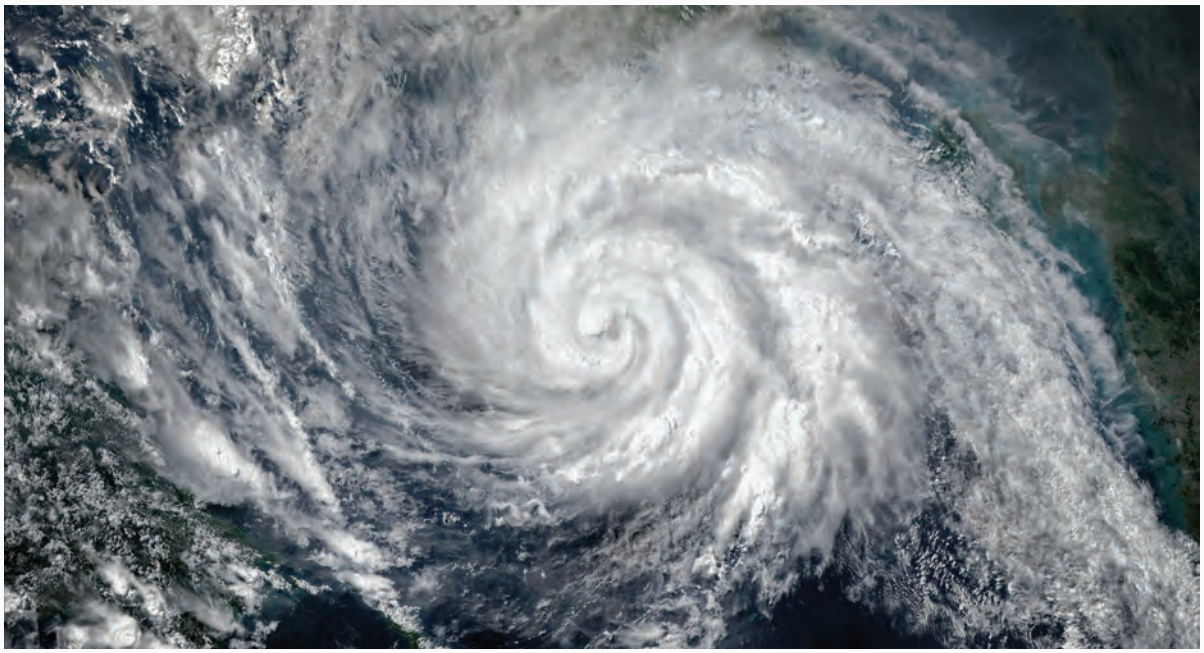
The transport industry is currently fragmented in its approach to climate resilience. By having an overarching governance structure, key actors and policy makers can work together to set a destination understood across the industry and promote real progress. This would create a single structure under which organisations can collaborate and learn from one another to meet resilience targets.

How it helps

Agreeing on a shared goal for climate resilience between organisations fosters collaboration and builds resilience into networks. This can be achieved through methods like frameworks, which set out consistent goals and are operated by international organisations. An alternative would be a mandate set out at national level informed by meetings and agreements between transport experts from local authorities and individual companies. The key stakeholders in the sector would be able to shape a consistent aim which suits their organisations and have the opportunity to build on those to create the best possible outcomes.

Case study:

Assessing the progress and impact of Federal climate adaptation: Developing climate resilience indicators and metrics



Developed by the US White House Council on Environmental Quality in June 2024, this paper outlines the development and implementation of climate resilience key performance indicators.

It supports the Federal Climate Adaptation Plans for 2024-2027, which includes a common set of indicators and metrics to enhance understanding, track progress, and identify gaps in Federal climate adaptation and resilience efforts. The metrics are divided into process-related and outcome-related categories and focus on five aspects: climate resilience integration, data management systems, comprehensive climate hazard addressing, Federal assets and supply chains and staff training. For example, a common goal is policy review and revision to ensure 100% of climate adaptation and resilience policies incorporate nature-based solutions, mitigation co-benefits, and equity principles by July 2025.

With Trump's administration expected to deprioritise climate action, including withdrawal from the Paris Agreement, this program may face significant weakening. However, its goals have endured initial funding cuts in the presidency's first 100 days.

Further reading:
www.sustainability.gov

Achieving climate resilience

Build cross-sector collaboration

Overview

Collaboration is one of the single most important factors in creating a resilient transport system for the UK.

There are multiple organisations involved in the day-to-day running of transport networks, as well as managing passengers, freight and the land within which transport infrastructure sits. Only effective collaboration between all partners can create a system truly resilient to climate change. Weather hazards do not stick to administrative boundaries, and as such the reactive responses to them must involve those who are affected from across the system. Collaboration is a key aspect of mitigating the potential cascade failures the transport system is uniquely vulnerable to.

There is a wealth of data and knowledge within the transport industry on climate resilience, but it exists in a fragmented state, spread across organisations. The facilitation of knowledge sharing and bringing together expertise is an essential aspect of building climate resilience. Without this, the result is a fragmented approach that cannot hope to meet the challenges posed by climate change. Through collaboration and development of innovative joined up approaches, organisations will be able to build collective resilience and future proof their networks against hazards which are only becoming more frequent and severe as the climate continues to change.

Why it matters

There are significant challenges to achieving effective collaboration in the transport space, including siloed work environments, data protection and poor communication between different types of organisations. Siloed work environments are challenging as current policy and economic pressures leave teams without the scope or resources to look further afield. By working in this isolated manner, data, insights and methodologies are not shared, leading to repetition of projects and stifling innovation.

Identifying the biggest issues and most effective methods for combatting hazards requires good data. However, data collection and analysis often remain highly fragmented, as it is undertaken by different organisations working independently. In the UK there are 28 major train operating companies and an estimated 3,400 independent bus and coach operators. This creates a highly fractured landscape, with each collecting their own data. Without more collaboration on data sharing, understanding the efficacy of adaptation and mitigation becomes almost impossible.

Communication is the bedrock on which collaboration can be built, and an area where the transport industry could improve. Current weak partnerships between public and private organisations lead to a lack of understanding and collaboration, resulting in fractured approaches to resilience. Improving communication on ongoing projects will enable targeted research and maximise the benefits of current initiatives.

What to do

Leadership to encourage growth:
Innovative and engaged leadership can make a difference in active collaboration. Empowering leaders to encourage resilience as a key priority gives organisations the mandate to work together and collaborate on innovative solutions. Shifting the mindset from competition to collaboration must start with leaders willing to engage and think holistically about their resources and climate resilience.

Data democratisation:
By making data processing tools available to the wider public, more people can use data to research, innovate and drive change. Also, building on existing figures is key to understand climate trends. If data is collected in a coordinated and focused way, it becomes better processed and accessible. This enables intermediaries such as data observatories to help leverage data to increase resilience. Transport for London, a leader in open data practices offers freely accessible data to encourage innovation and collaboration.

Cross collaboration through intermediaries:
Collective networks can address problems better by inviting all parties into the same room. Transport resilience needs a holistic solution, requiring experts across disciplines to meet and address issues. Collaboration also improves knowledge, data comprehension and ability to inform and engage, contributing to a more holistic approach.

How it helps

Collaboration across the industry provides the opportunity to tackle problems not as independent organisations but a consistent whole, bringing together expertise and resource from across the industry. This unlocks better networks and allows further resilience innovation to build on past work, improving outcomes through combined knowledge.

Bringing industry leaders together, the London Transport Museum Interchange programme exemplifies how industry collaboration fosters positive outcomes, builds networks, and addresses resilience challenges that cannot be tackled individually.

Case study:
Marylebone Flyover Rain Gardens


Marble Arch London BID & Michael Pilkington

Delivered by Transport for London with support from Greater London Authority, Thames Water, Westminster City Council, and the Marble Arch London Business Improvement District, the Marylebone Flyover Rain Gardens transformed a disused underpass into central London's largest sustainable drainage systems. The scheme was designed to manage around 3,500m² of surface water run-off, increasing flood resilience while enhancing biodiversity with over 1,100 plants and shrubs, 2,300 bulbs and 11 new trees.

Collaboration was a key element of its success, with Transport for London leading delivery, Greater London Authority and Thames Water providing funding, and the Marble Arch Business Improvement District committing to long-term maintenance. Engagement with Westminster City Council and local residents, ensured the project aligned with community priorities and improved public spaces.

This initiative demonstrates the power of collaboration across public bodies, businesses and communities to implement climate resilience measures and sustain their long-term impact. Clear roles, shared funding and community engagement were essential to ensure it has a lasting value for both the environment and the local community.

Location:
www.google.com/maps

Achieving climate resilience

Implement resource and finance effectively

Image: ©Transport for London

Overview

Funding and financing resilience remains one of the biggest barriers to action.

In a world of tight public budgets and growing demands on local authorities, transport organisations and asset owners, resilience projects often lose out to more immediate priorities. This is one of the main reasons strong adaptation proposals struggle to get off the ground.

There are three key steps to enabling investment for resilience: quantify asset damages and service disruption related losses; calculate economic, social and environmental co-benefits of resilient solutions; and create economic and financial mechanisms to have return on investment. The insurance sector can support resilience by offering lower premiums or faster payouts for climate-adapted infrastructure, encouraging a 'build back better' approach.

At the same time, many local authorities and transport organisations face acute resourcing challenges, with limited in-house expertise and capacity to develop robust, long-term adaptation projects. Both targeted support and partnerships are essential to overcome these barriers.

Why it matters

The benefits of resilience are often fragmented, spread across multiple public and private stakeholders, such as residents, businesses, public services and infrastructure operators. Organisational culture, privately held data and independently governed investment processes make it systemically difficult to identify beneficiaries and accurately align incentives for investment.

Unlike typical investments, adaptation projects rarely generate direct revenue streams. Instead, the returns are often in the form of avoided losses or enhanced wellbeing, which are harder to monetise. For this reason, constructing a compelling financial case often becomes a challenge, particularly for private investors, and can limit the appetite for funding unless public value or long-term savings are explicitly accounted for. In combination with the above, in the current paradigm, it is not certain that the organisation who makes the investment will receive a sufficient level of benefit to justify the spend.

In addition, councils and transport organisations lack the capability to develop long-term adaptation projects. Resources are often planned around near-term objectives with high certainty and are shared with essential services like health and social care which take priority. Expertise and information in areas such as climate risk, financing and business case development is limited, which complicates building robust proposals that could engage the right partners and secure alternative funding to future-proof transport infrastructure.

What to do

Leverage the insurance industry:
By adjusting premiums or offering better terms when infrastructure is designed or upgraded to withstand extreme weather, the industry can promote a 'build back better' approach, leading to lower long-term premiums. These benefits can be reinforced by faster, trigger-based payouts when thresholds like temperature extremes are exceeded, allowing for a quicker recovery and greater certainty. Insurers can also share loss data and risk modelling with public bodies to target investment and improve long-term planning.

Innovative partnership models:
Public-private partnerships offer a practical way to address the resource and skills gaps facing many local authorities. They allow councils to access private capital and expertise that may not be available in-house. This includes technical knowledge around climate risk, project design and delivery, as well as financial modelling and long-term asset management.

Financial instruments:
Green bonds enable governments and infrastructure providers to tap into private capital markets. It is believed that there is strong potential for their use in the transport sector,[21] directing investment towards projects with environmental benefits such as heat-adapted rail. A newer subset, resilience bonds can fund risk reduction infrastructure projects by converting avoided losses into revenue streams through a resilience rebate, incentivising such projects.

How it helps

Unlocking investment opportunities can create green growth, from creating skilled jobs in construction and maintenance to driving innovation in sustainable infrastructure. It also supports wider goals, from reducing inequality to meeting climate and development targets such as the UN Sustainable Development Goals.

Over the long term, proactive investment in resilient infrastructure will generate savings in reactive maintenance and repairs, a more stable supply chain and a better environment for circular economy and efficient design. A less volatile spending profile in repair costs and confident supply chain will lead to more generalised construction efficiencies for the public purse.

'Build back better' insurance policies are enormously valuable to the transport industry and private property owners alike. Rather than leaving many homes in flood plains uninsurable, for example, build back better enables the installation of resilience measures to limit losses in future events. This provides security to both homeowner and insurer, who is able to avoid raising premiums to cover increasingly frequent claims. In the transport context, there are generally no such insurance policies, however, the build back better principle must be applied to investment policies at the point of repair to provide greater protection and access resilience to surrounding communities.

Case study:
UK's Green Financing Programme

Part of the UK's Green Financing Programme, the Green Gilt was the UK's first green sovereign bond issued at scale. A step forward in the development of the global green bond market, it demonstrates how financial instruments can be designed to encourage investment in tackling climate change. The programme covers six types of expenditure, ensuring transparency and accountability in the allocation of funds. To support further the transition to a green economy, the initiative also comprises the NS&I's Green Savings Bonds.

In the financial year 2023-2024, these green financing instruments raised £10.9 billion, with an additional £1.9 billion carried over from the previous year, making a total of £12.8 billion. With climate change risks increasing its frequency and severity, and transport systems being a significant contributor to greenhouse gas emissions, clean transportation and climate change adaption projects are part of the green expenditures. Through these instruments, the UK Government encourages investment in initiatives aimed at creating a more sustainable and resilient transport system.

Further reading:
www.gov.uk/government/publications

Achieving climate resilience

Inform decisions through data and innovation

Overview

The UK has a long legacy of transport innovation, from the world's first underground railway to modern advances in mobility, much of it showcased by the London Transport Museum.

With data and digital at the heart of the future of transport, it is time for the industry to leverage technology and innovation to increase resilience. To understand the true risks facing our infrastructure and prevent failures before they occur, we need accurate, timely and accessible data. Good data enables smarter investment decisions, better operational responses and clearer communication between stakeholders. Crucially, it provides a clearer picture of the costs of inaction and the value of early, targeted investment in resilience.

The third Climate Change Risk Assessment [22] highlights a lack of quantification around many climate related risks. While toolkits such as the Transport Analysis Guidance developed by the Department for Transport sets out monetary values for project appraisal, these cannot yet be applied due to gaps in climate modelling. Without robust evidence and ex-post evaluations, the benefits of resilience remain under-recognised, limiting the case for action. However, we cannot afford to wait for perfect data. Even if outcomes are uncertain, not using the evidence we have now to take action is the greatest risk. Progress must go hand in hand with continued investment in better data and preparedness to fail, adapt and learn.

Why it matters

Data on climate risks to transport is often incomplete, qualitative in nature or not collected at all. Where data does exist, it is often not attributed to specific climate risks, which is key to understanding the cost of inaction and the benefits of adaptation. Without this attribution, it becomes difficult to build a compelling case for investment in measures that mitigate the impacts of specific climate hazards. Furthermore, data is not consistently processed, nor is it shared openly between stakeholders that need it most.

With transport systems often relying on data from multiple sources, which may not be easily integrated or interoperable, this fragmentation can hinder the ability to create a comprehensive understanding of vulnerabilities and resilience needs across the network.

Not only is the collection and monitoring of real-time data essential to respond to disruption, but also its implementation and maintenance. With climate events becoming more frequent and severe, the lack of updated data can delay responses, exacerbating the impact of extreme weather on transport infrastructure.

What to do

Standards for data collection:
Every infrastructure project should be required to gather data on performance and failures, explicitly attributing disruptions and events to build a picture of recorded costs across different weather conditions. Standardising and mandating this process would build a consistent, bottom-up evidence base for action, with clear monitoring and evaluation processes to assess effectiveness and inform decision making.

Real time data and monitoring:
Investing in advanced monitoring technologies and infrastructure that enable real-time data collection and analysis and use predictive analytics can help anticipate and mitigate potential disruptions. By leveraging technologies such as Internet of Things sensors and artificial intelligence-driven analytics, transport systems can gain real-time insights into their operational status and potential vulnerabilities, allowing to take proactive measures.

Leverage current data, for now:
Existing operational data, incident reports and climate projections should be used to prioritise resilience measures in the most vulnerable and at the highest risk areas. Waiting for complete datasets will cause greater delays and damage. The proactive use of available data empowers decision makers to act, learn from experience and refine strategies as better data becomes available.

How it helps

Better data collection and attribution enable decision-makers to prioritise high-impact interventions, target funding more effectively and build stronger investment cases. This unlocks the creation and use of data platforms, which can translate complex datasets into actionable insights for decision makers, driving innovation and supporting a shift from reactive responses to proactive, evidence-led planning.

Case study:
Water catchment assessment with NatureInsight®

NatureInsight® is an innovative tool developed by Arup and SCALGO to transform how organisations address climate risks through nature-based solutions. Covering all of Great Britain, it scores the suitability of ten nature-based solution types at each location and assesses their potential to boost carbon sequestration, create habitats, and manage water flows. With cost estimates included, users can optimise interventions for maximum impact within set budgets, supported by advanced analytics and local insights.

Built into the Scalgo Live platform, NatureInsight® combines sophisticated catchment modelling, hydrology data, and flood risk analysis to guide for smarter, greener investments. For transport operators facing growing flood risks, it pinpoints vulnerable road and rail assets and supports proactive drainage management strategies. By unlocking the power of local landscapes and blending this with infrastructure design, NatureInsight® helps protect communities, strengthen climate resilience, and deliver lasting value for both people and the environment.

Further reading:
www.arup.com/services/digital-solutions

Achieving climate resilience

Adopt a resilience mindset

Overview

The way climate resilience has been thought about within the transport industry, and more widely in society, has often been associated with the costs, ignoring the benefits.

A significant mindset shift is needed to reframe the resilience conversation. This new perspective acknowledges the power of collective action, alongside demonstrating the positive outcomes of adopting climate resilience. It takes a step back and shifts the entire resilience narrative to prove both the primary economic benefits and the secondary co-benefits to factors such as health and wellbeing. Resilience will be reframed not simply as a reactive cost, but as something that can be actively pursued to improve quality of life.

Transport resilience should also be empowering in its very nature, engaging those most affected by hazards. Feeling overwhelmed in the face of a changing climate is common, which can lead to passivity and a feeling of hopelessness. A shift in mindset away from helplessness and towards ownership could have a huge impact on both behaviours and trust in our transport system, improving the lives of communities.

Why it matters

Resilience is currently seen as all costs with few benefits, spreading the belief that whatever we do will make little to no impact. Addressing these problems will require a combination of public relations, policy and a shift in how resilience is discussed at the highest level. A more balanced short-term and positive long-term narrative needs to be created, encouraging resilience as standard in every transport business case.

The challenge of climate change being an existential threat is also a significant blocker to progress in the resilience space. If individuals feel like there is nothing they can do about weather hazards, they are far less likely to implement change. The message that the individual can have an impact on climate resilience, through their own agency within organisations and also in their individual life needs to be reinforced. Adaptation and increased resilience can also bring greater equality and opportunity for social mobility, aligning with government aims.

What to do

Change the narrative:

Adapting the narrative of resilience as a benefit is the first step towards improving the primary resilience mindset. By engaging with local communities and displaying the positive impacts of climate resilience beyond withstanding risks, a more holistic case can be shaped. The story needs to demonstrate that investing in resilience leads to healthier, greener and more active communities, and benefits beyond finance. This is in addition to the impact it will have creating local green jobs and expanding local skills.

Move from ‘sweat’ to ‘share’ the asset:

Changing transport assets approach from spend avoidance to long-term collaborative investment will improve value and returns over a longer time. Adopting a resilience mindset means embracing resilience in infrastructure right from the beginning of a project, establishing its importance and building on it throughout the project lifecycle. This requires a change from seeing it as a cost at the end of a project, to a key part of realising the true economic and social value of transport infrastructure.

Community engagement and integration:

A shift in mindset needs to extend beyond those building and operating transport infrastructure, and encompass the communities who will be using the infrastructure. Engagement on resilience, demonstrating its benefits and thereby its necessity, can improve the buy-in of local people. Securing this buy-in enables a more holistic approach to truly deliver social value.

How it helps

Adopting a resilience mindset creates the opportunity to change the currently ongoing conversation around resilience. It provides the ability to engage with individuals at all levels, from community groups to government, demonstrating the myriad benefits climate resilience could bring. Through building in resilience from the beginning of projects, alongside demonstrating the co-benefits resilience brings, there is the opportunity to empower our local communities, and build them to be healthier and happier moving forwards.

Case study:

Accounting for the effects of climate change: HM Treasury's Supplementary Green Book guidance

Supplementing its Green Book, HM Treasury's additional guidance provides detailed instructions for analysts and policymakers to ensure that policies, programs, and projects are climate-resilient. It highlights the importance of incorporating climate risks assessments, resilient policy options, and estimated costs and benefits from the outset, offering a step-by-step approach to climate-resilient appraisals.

The document also provides a hazard-exposure-vulnerability framework to identify, evaluate and develop policy options. In addition, it stresses the importance of considering the varying impacts of climate change on different groups as well as the wider benefits of adaptation measures.

Giving practical examples and case studies to illustrate its application, the HM Treasury's Supplementary Green Book guidance aims to change the current mindset and practices in policy appraisal for ensuring climate resilience.

Further reading:
www.assets.publishing.service.gov.uk

04

Conclusions

Resilience means ensuring that the transport systems we rely on today will remain reliable for tomorrow.

It is building trust that they will hold firm in the face of growing climate pressures. It implies establishing a network that can function to some level all year round, that is predictable enough to be trusted by users across the network.

Building the reputation of a transport network that is functional in all but the most extreme weather conditions. By developing a relationship of trust and a system they can rely on, both physical and social mobility can be improved.

Alongside this, well integrated transport systems are drivers for economic growth, and are vital for the communities connected by them. They provide increased access to job opportunities, allow connection for leisure and remove economic pressure on those who cannot afford or are unable to drive.

These infrastructure assests are also key to maintain our urban environment. Making them resilient to climate hazards ensures they can continue to serve their local communities and promote economic growth in the area surrounding key pieces of infrastructure.

To achieve these goals, the transport industry must address obstacles and implement some key changes: establish common goals, build cross sector collaboration, adopt a resilience mindset, inform decisions through data and implement resource and funding effectively.

These measures should set the path to a climate-resilient transport network, empowering communities across the UK and beyond to thrive in a changing climate.

05

Appendices

In this section:

Appendix A
About Interchange event series

Event 1:
Resilience vs Risk: Making the case for transport's future

Date: Thursday, 5 December 2024
Location: London Transport Museum, London

This event focused on making the case for long-term resilience in the context of present-day safety and reliability risks from aging assets. Bringing together experts across the industry, we discussed key challenges of the UK's transport network including vulnerability across modes and sectors, capabilities to support proactive planning and investment in resilience and raising the profile of the problems without supporting evidence and data.

Event 2:
Building transport's resilient future

Date: Thursday, 16 January 2025
Location: The Crypt, London

During this evening, we discussed collaboration across the public and private sectors to deliver data-driven climate-resilient projects that meet neighbourhood economic and social needs. Given the economic pressures facing local authorities, Network Rail and the Treasury, our experts also explored alternative funding sources and how resilience standards and legislation may change funding allocation decisions.

Event 3:
Rethinking resilience

Date: Wednesday, 12 February 2025
Location: London Transport Museum, London

In this session, we deep dived into the opportunities for using future tech, collaboration, and nature-based solutions in climate resilience, drawing on existing global solutions to climate risk. Our experts also discussed whether simplifying standards could enable faster, more effective action in building a resilient transport network for the future, and the possible risks of this.

Event 4:
Unlocking data to break down funding barriers

Date: Thursday, 13 March 2025
Location: Arup, London

This workshop addressed the existing barriers to tackle extreme weather events in a proactive way despite growing recognition of their detrimental impact on our transport infrastructure. Using two real-life projects as case studies, our speakers showcased how to overcome some of these challenges to help public and private organisations build a compelling case for investment, secure public and private funding and implement resilience measures such as nature-based solutions.

We would like to thank the following organisations for joining our event series.

It was a pleasure to bring together experts across the transport industry to discuss ideas and share best practice on how to progress on the path to a climate resilient transport network.

– Amey
– Broadfield UK
– Campaign for Better Transport
– Capita Procurement Solutions
– Chartered Institution of Highways and Transportation (CIHT)
– Cleshar Contract Services
– ClientEarth
– Cubic UK
– Department for Transport
– First Bus London
– Foster and Partners
– Hemiko
– Mott MacDonald
– National Highways
– Network Rail
– PA Consulting
– Palantir Technologies
– Places for London
– Port of London Authority
– QBE International
– Rail Delivery Group
– Rock Road
– Saga Tenix AS
– Stagecoach London
– Telent
– Transport Focus
– Transport for London
– University of Birmingham
– Worldline
– Yunex Traffic

Appendix B
About Interchange programme partners

London Transport Museum
Programme leader

London Transport Museum's purpose is to ignite curiosity to shape the future. The Museum is situated in the heart of Covent Garden and filled with stunning exhibits; the Museum explores the powerful link between transport and the growth of modern London, culture and society since 1800.

Historic vehicles, world-famous posters and the very best objects from the Museum's extraordinary collection are brought together to tell the story of London's development and the part transport played in defining the unique identity of the city.

The Museum is a charity and the world's leading museum of urban transport and a place for everyone to come to understand and enjoy the story of London's journey. No other capital city is defined and shaped so much by its transport as London. Yet the scale of influence of transport can be invisible to those who use it every day. The Museum's collections, together with its lively events and learning programme are a window into the past, present and future of how transport keeps London moving, working and growing, and makes life in our city better.

www.ltmuseum.co.uk

Arup
Content partner

Arup advises on, plans and designs the future of the built environment. The firm's purpose is to create safe, resilient, and regenerative places that enable current and future generations to thrive.

With technical and advisory expertise across more than 150 disciplines, the global consultancy brings a Total Design approach to its work. This creative and collaborative approach drives its members to take a broad and holistic perspective, delivering creative, practical and effective solutions. This is how Arup shapes a better world.

In the transport industry, the firm is at the forefront of developing resilient and adaptive solutions for addressing the challenges posed by climate change. With expertise across rail, roads, aviation and maritime, Arup leads the creation of adaptive infrastructure that enhances the sustainability of transport networks, reducing environmental impact, empowering communities and encouraging economic growth.

www.arup.com

Gowling WLG
Programme partner

Gowling WLG is a sector-focused international law firm with in-depth expertise and experience in key global sectors, including transport and infrastructure, energy, tech, advanced manufacturing, government and real estate. It is ranked in the Legal 500 UK Green Guide, a new guide by Legal 500, designed to recognise the top law firms advising on issues around climate change, governance and sustainability.

The firm believes that legal matters are people matters and that it takes closer relationships between people and teams to get to the best results, in the right way. A longstanding Corporate Member of London Transport Museum, the firm takes pride in sponsoring initiatives that align with its values and supports communities.

Gowling WLG has committed to the UN Global Compact and obtained certification for quality (ISO9001), environment (ISO14001) and energy (ISO50001) management systems. Additionally it is a founder signatory of Legal Charter 1.5 to catalyse carbon reduction activity in the legal sector.

www.gowlingwlg.com/en

Hitachi Rail
Programme partner

Hitachi Rail is driving the transition to sustainable mobility, partnering with customers to rethink and transform how people and goods move. Its mission is to help deliver more connected, smooth, and sustainable transport experiences for every passenger, customer and community.

With a strong local presence and a global reach, Hitachi Rail combines deep expertise across every part of rail and urban mobility, from designing and manufacturing high-speed and commuter trains to pioneering digital signalling, smart operations and integrated mobility solutions.

Part of the wider Hitachi Group and renowned for Japan's iconic high-speed trains, Hitachi Rail leverages advanced digital and AI capabilities to accelerate innovation and develop future-ready technologies on the journey toward net zero mobility.

www.hitachirail.com

Appendix C
Endnotes

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