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ABOUT THE RESILIENCE SHIFT

The Resilience Shift exists to inspire and empower a global community to make the world safer through resilient infrastructure. More people than ever depend on the critical infrastructure systems that provide essential energy, water, transport and communications services, and underpin food, healthcare and education. When this infrastructure fails the consequences can be catastrophic.

Supported by Lloyd’s Register Foundation and Arup, the Resilience Shift provides knowledge and tools for those responsible for planning, financing, designing, delivering, operating and maintaining critical infrastructure systems. Our aim is to ensure infrastructure systems are able to withstand, adapt to, and recover quickly from anticipated or unexpected shocks and stresses - now and in the future.

DEFINING RESILIENCE

Resilience is the ability to withstand, adapt to changing conditions, and recover positively from shocks and stresses. Resilient infrastructure will therefore be able to continue to provide essential services, due to its ability to withstand, adapt and recover positively from whatever shocks and stresses it may face now and in the future.

ACKNOWLEDGEMENTS

This primer is based mainly on a series of in-depth face-to-face and telephone interviews of practitioners and policy-makers working on improving resilience across the road industry in Europe and the United States. The authors are grateful to all the stakeholders that provided their time and knowledge to provide input for this primer. These included representatives from Highways England, Transport Scotland, Department for Transport, Rijkwaterstaat, Norwegian Public Road Authority, John Dora Consulting/Infrastructure Operators Adaptation Forum, UK Roads Board, Local Government Technical Advisory Group, Transport Focus and other organisations which prefer to remain anonymous. We would like to thank Juliet Mian, Technical Director of the Resilience Shift. Any errors or omissions are solely the responsibility of the authors, not the contributors.
Foreword

Building resilience of critical infrastructure requires decision-makers working in different industry sectors to understand ‘what’ can be done, ‘why’ it should be done, and ‘how’ to put it into practice. Our work to date has told us that key stakeholders are often either unaware of the value that resilience can bring or are constrained by a lack of resources or support in terms of how to embed and enhance resilience.

This primer is a brief document introducing the elementary principles of resilience relevant to the roads sector and is part of a body of knowledge, tools and approaches that the Resilience Shift is producing, funding, and curating, intended to help those responsible for the financing, planning, design, delivery, operation and maintenance of critical infrastructure systems to shift practice. Our vision is to contribute to a common understanding across critical infrastructure sectors of what contributes to resilience and how it can be achieved in practice.

Building resilience into your infrastructure systems, across your value chains, will allow you to prevent or mitigate against shocks and stresses that you identify, and to respond better to those events that you can’t predict or avoid.

We’re delighted to have supported the team at TRL in producing this primer.

The Resilience Shift team

This primer is a ‘companion document’ to the rail primer. The two have been produced in parallel, and sector specific insights are presented as well as findings that are common to both sectors.
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We all want a resilient transport system, but what does that actually mean and how does everyone in the industry work together to make it happen? There is no simple solution to this complex problem, but the application of carefully considered levers at different points in the value chain can make a real difference.

Effective road transport underpins the economic and social functions of society, and disruption can cause a cascade of impacts including limiting or preventing access to jobs, education and leisure, and essential services such as healthcare. In severe cases, road transport disruptions can even affect the GDP of a country. Many transport organisations are working to improve resilience, however, consistently including it throughout the value chain is challenging.

This primer identifies a number of different areas where consideration of resilience can help to create a safer, more reliable and robust road network. Based on a series of interviews with practitioners and policy-makers in Europe and the United States, examples of good practice are presented highlighting what can be done to incentivise improvements to resilience. It is hoped that this primer enables readers to learn from their peers and that they are encouraged to become more resilient.

The primer was produced as part of the Resilience Shift initiative funded by the Lloyds Register Foundation and managed by Arup. In producing this document, we saw common problems across many stakeholders, and identified a number of innovative solutions being used in practice.

No one organisation has all the answers, but each has addressed different aspects of resilience in different ways. Resilience needs to be considered across different activities, project stages and organisations, with many different stakeholders working together to embed it in to everyday practice. Infrastructure owners, government, regulators, suppliers and users of the network each have a role in applying levers to increase resilience. Such levers might include the provision of specific requirements in planning documents, design standards, procurement processes and other regulatory and influencing documents, and employing political and media pressure to promote awareness.
Our recommendations

Six areas of action are identified:

- Changing mind-sets
- Embedding resilience in organisational processes and procedures
- Providing leadership and accountability
- Encouraging systems-thinking and collaboration
- Disaster management
- Risk management

Recommendations and examples of levers are provided under each of these areas in section 6. If road transport is to become more resilient, each area has to be addressed. Learning from the experiences of other organisations that face similar challenges is a vital part of this.
Introduction

Sea Cliff Bridge in Sydney, Australia (Photo by William Karl)
The purpose of this primer is to equip practitioners in the road industry with knowledge that will help you embed resilience in your organisations, by having access to examples and case studies from your sector, and by understanding what drives changes in practice.

They were selected partly as these countries are active in the area of resilience and also because they provide examples of different organisational structures and therefore have different levers. The interviewees provided examples of incentivisation of resilience from their respective countries which are used to illustrate the described levers, but the general principles described are transferable to any country.

A list of questions (one for practitioners and one for policy-makers) was prepared and circulated to the interviewees before the interview along with some introductory information. The interviewers used these questions as a prompt, but were also flexible tailoring the questions to the individual interviewees. The majority of interviews were carried out by telephone, but a few were carried out face-to-face. On average the interviews took around 90 minutes and all interviews were recorded. Some interviewees provided written documents and the interviews were supplemented by literature review and the teams experience of the industry.

The TRL project team also prepared the rail resilience primer, carrying out the road and rail interviews concurrently. Some interviewees’ roles covered the organisational structure and levers are different, therefore it was decided to produce separate primers. There are transferable approaches and so some duplication across the two primers where appropriate, but with different examples of implementation.

Although road and rail are discussed in separate primers so as to reach different sets of decision-makers, it is important to consider the transport system as a whole and the interdependencies between modes.
Defining resilience in the road industry
Why a resilient road network is important

Transport plays a vital role in society, and its effectiveness directly influences a country’s economic and social success as highlighted by the Eddington Study (2006) in the UK. The majority of short to medium distance passenger and freight transport is carried out by road. Roads provide access to jobs, essential services such as healthcare and enable goods to reach consumers and manufacturers. Mobility is something the majority of us take for granted until something occurs to limit it.

Multiple natural and anthropogenic hazards can damage infrastructure and impede travel. In the absence of serious injuries and fatalities, the real impacts of these events are economic and social. These include the cost of transport delays and diversions and the severance of access to and from communities for services and markets for goods; employment, health and educational opportunities; and social activities. Widespread, long-term disruption to travel can have a significant economic impact.

For example delayed journeys in England as a result of the harsher than average weather in the winter of 2009/10 was estimated to cost around £280 million a day, and the event overall to have reduced GDP by 0.5 percent (House of Commons Transport Committee, 2010).
What does the term ‘resilience’ mean to the road industry?

There is agreement within the road industry that improving resilience constitutes both increasing the ability of infrastructure to withstand potential threats and also the capability of the system to rapidly recover from disruptive events. When communicating about resilience, it is necessary to be sure that everyone has the same understanding of what is trying to be achieved. In this primer, resilience is taken to mean a long-term holistic perspective of any threat to the functionality of the transport system.

**EXAMPLE RESILIENCE DEFINITIONS**

**UK Cabinet Office (2011)** - “Resilience is the ability of assets, networks and systems to anticipate, absorb, adapt to, and/or rapidly recover from a disruptive event.”

**Federal Highway Administration (FHWA) Order 5520 (2014)** - “Resilience or resiliency is the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.”

**UK Road Liaison Group Code of practice ‘Well-managed highway infrastructure’ (2016)** - “Resilience planning is not just about the physical resilience of the highway infrastructure but also about how disruption is managed and the speed of recovery. Climate change and other rising risks may increase the frequency with which Highway Authorities will have to respond to severe weather emergencies. Authorities should establish, in consultation with others, including service providers, emergency services and relevant agencies such as the Environment Agency, or equivalent, operational plans and procedures to enable timely and effective action to mitigate the effects of such weather emergencies as they affect the highway network.”

Resilience Shift - see definition used by on p.3
Quantifying resilience

The benefits of improving resilience include an improvement in safety, and a reduction in travel disruption and infrastructure damage. Quantifying these benefits in economic terms can help to make the business case for improving resilience. Importantly, the benefits of increased resilience are an avoidance of future costs, which is difficult for some to accept as an economic incentive for action especially as it is difficult to prove the cost would have been incurred if no action had been taken. Cost-benefit analysis (CBA) can help to make the case for preventative action. CBA is structured to monetise the avoidance of future costs, define these as benefits, and compare these benefits against costs of specific actions. Where benefits outweigh costs, decision-makers should be incentivised to invest. However, the boundaries and appraisal period of the CBA are particularly important when evaluating actions to improve road resilience.

- **Inclusion of wider costs** - The main costs of improving resilience are borne by the infrastructure owners, and they are most interested in the future costs and benefits affecting their own budget. However, the wider socio-economic costs of travel disruption are far larger than the economic costs borne by the infrastructure owners so not including these can undervalue the benefit of resilience measures.

- **Appraisal periods and discount rates** - Payback times for preventative action can be long-term (i.e. outside budgetary timeframes or traditional appraisal periods) and discount rates reduce the value of future costs compared to initial costs. Limiting the analysis to direct costs and short appraisal periods can fail to take into account the full benefit of an action.

- **Inclusion of risks and uncertainty** - Risks are not always fully incorporated into economic appraisal, and are often underestimated. This can mean the true costs of inaction are not considered. Whilst CBA can help to highlight the benefits of greater resilience, it is often not sufficient to change behaviour. In the road industry, concepts such as value engineering can be misapplied to reduce initial costs by removing aspects of a project which may be required only rarely (i.e. to address low frequency, high impact events). More direct incentives need to be created to counteract this.

"The market will never provide resilience because the market always goes for efficiency.

Source: Anonymous"
Embedding resilience in road infrastructure and its management

Road infrastructure, includes a wide range of asset types such as road pavement, bridges, retaining walls, tunnels, earthworks and slopes, gantries, drainage, ITS (Intelligent Transport Systems), depots and so on. Infrastructure cannot be separated from the other aspects of the operation and governance of the road network and the interdependencies with other sectors. It is the resilience of the system as a whole which is important to the user.

Figure 1 depicts a typical value chain of a large infrastructure project, showing the different project stages from proposal to delivery. At each stage decisions are made which influence the resilience of the infrastructure, often involving different stakeholders working in collaboration.

Initial proposal stage - decision-making is centred around the policy need and how best to meet this. This includes the case for investment, the benefits expected from the project and the major options available e.g. on alignment. These types of decisions are normally made by national and local government, and are influenced by local communities’ groups and businesses. It is more effective if resilience is fully integrated in a project from the start, for example by inclusion in the project objectives and being considered in alignment options, so this is an important stage in the value chain.

Planning and appraisal stage - options are further developed and then evaluated in terms of their economic, social and environmental impacts. This is normally carried out by the infrastructure owner in conjunction with government, and follows national appraisal guidelines. The resilience of both the infrastructure being built/ upgraded and the impact the project has on the resilience of other infrastructure and communities should be considered. Planning consent often involves public consultation, so any group or individual is able to influence the project.

Detailed design – is carried out on the selected option, with decisions being made on design and materials by the infrastructure owner and (depending on the type of procurement) supplier. Procurement decisions are also made by the infrastructure owner in terms of procurement type, supplier requirements and supplier selection. Resilience can be embedded by using more robust materials and design better able to withstand different hazards, by incorporating features which make it easier to repair if damaged, or update if conditions change, and by including it in procurement processes.

During construction - the planned design and materials may need to be adjusted by supplier, with the agreement of the infrastructure owner, to fit the actual conditions. When complete, the infrastructure owner signs-off the new asset and it enters into use. Although, most major decisions have been made by this phase of the project there are still opportunities for modifying designs to increase resilience. Also care needs to be taken that aspects included in the design to increase resilience are not eroded due to pressures on time and budget.

Maintenance and operation - decisions relating to the maintenance of deteriorated infrastructure and the operation of the network are made by the infrastructure owner and their supplier. Resilience can be included in prioritisation of maintenance and improving response to incidents.
Improving resilience to the variety of hazards facing road networks requires integration into decision-making at all points of the infrastructure lifecycle, and there are a range of different types of organisation that contribute to these decisions (see Table 1). The interactions between these stakeholders are particularly important for determining resilience.

### STAKEHOLDER TYPE

<table>
<thead>
<tr>
<th>Description/Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STAKEHOLDER TYPE</strong></td>
</tr>
<tr>
<td><strong>USERS OF THE INFRASTRUCTURE</strong></td>
</tr>
<tr>
<td><strong>OWNERS/OPERATORS OF THE INFRASTRUCTURE</strong></td>
</tr>
<tr>
<td><strong>GOVERNMENT DEPARTMENTS/ MINISTRIES</strong></td>
</tr>
<tr>
<td><strong>REGULATORS/MONITORS</strong></td>
</tr>
<tr>
<td><strong>EMERGENCY SERVICES</strong></td>
</tr>
<tr>
<td><strong>OTHER GOVERNMENT AGENCIES</strong></td>
</tr>
<tr>
<td><strong>LOCAL GOVERNMENT/ MUNICIPALITIES</strong></td>
</tr>
<tr>
<td><strong>CONTRACTORS/ SUPPLIERS/OPERATING COMPANIES</strong></td>
</tr>
<tr>
<td><strong>COMMUNITIES AND LOCAL BUSINESSES</strong></td>
</tr>
<tr>
<td><strong>TECHNICAL ADVISORY BODIES</strong></td>
</tr>
<tr>
<td><strong>VEHICLE MANUFACTURERS</strong></td>
</tr>
<tr>
<td><strong>EXTERNAL FUNDERS</strong></td>
</tr>
</tbody>
</table>

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*Table 1:*

Types of road stakeholders
3 Vulnerabilities in the road industry
Road infrastructure has always been subject to a wide range of threats to its physical condition, safety of users and level of service. However, in today’s society the number of threats and the potential level of impact are greater than ever. Increasing travel demand, more complex and interconnected networks and ageing infrastructure combine to make the impacts of transport disruption felt throughout society.

As discussed in Chapter 2, road transport is a vital enabling sector, and disruption can produce a cascade of impacts across different sectors:

- Operations may be cancelled and emergency services restricted as staff and patients cannot reach hospitals, putting lives in danger.
- Wide-spread power outages as it is not possible to deliver fuel to power stations, affecting businesses and industry as well as private residences.
- Fuel shortages as hauliers are unable to reach refineries, potentially resulting in loss of mobility beyond the immediate roads affected.
- Freight disruption - affecting ‘just-in-time’ industry supply chains and causing a shortage of fresh food to supermarkets.
- Freight and passenger transport unable to reach major transport hubs, such as ports and airports, blocking imports/exports and international travel.
- School closures as staff are unable to get to work, affecting education and preventing parents, unable to find childcare at short notice, from working.
- Cultural and sports events cancelled, affecting social well-being and the economic viability of relevant industries.

Also a road closure on one road can cause severe congestion on surrounding roads. For example, an incident on a town bypass can produce crippling traffic congestion within the town, severely affecting urban transport including provision of bus and tram services.

The types of threat to the functionality of road can be divided into three types:

<table>
<thead>
<tr>
<th>Planned events</th>
<th>Such as major sporting events, political visits and known times of high demand such as public holidays.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unplanned events</td>
<td>Such as those due to severe weather flooding, landslides, avalanche, etc. (some warning of severe weather may be given by forecasts), earthquakes, fire, accidents, terrorism, fuel supply issues, pandemics, industrial action, trespass, infrastructure or vehicle failure.</td>
</tr>
<tr>
<td>Changes</td>
<td>In climate, technology, transport demand, mobility trends, political environment, public expectations and government requirements over time.</td>
</tr>
</tbody>
</table>

Each category of threat can create shocks (sudden events of short duration) and stresses (more gradual onset and longer duration) to the road infrastructure. The stresses may be short-term e.g. a week of standing water as a result of flooding or heavy traffic due to a sporting event, or long-term such as higher summer average temperatures or establishment of a new technology.
Planned events

Major sporting, demonstrations and political events can cause transport disruption, through weight of traffic and security restrictions. These are normally short-term, but in some cases can last several weeks. As they are known in advance, mitigation actions can be put in place for the period of expected disruption.

EXAMPLES OF DISRUPTION FROM PLANNED EVENTS

Olympic Games in 2012, London

During the 2012 London Olympic Games an additional three million journeys were expected (25% more than normal). Actions to mitigate the impact included a campaign to dissuade unnecessary travel in the affected areas, suspension of engineering work, dedicated games lanes, exit only metro stops and extra staff to direct passengers.

G8 Summit in 2013, Northern Ireland

At the G8 summit in Northern Ireland in June 2013 protests and security precautions caused travel delay and disruption. Extra buses and trains were arranged to reduce the number of road users and the public were warned to avoid the area if possible.
Unplanned events

The most disruptive events are the unplanned which could be due to severe weather, unexpected infrastructure failure or concern of failure, protests or strikes, terrorism and vandalism. Some examples of these are provided below. All the events described below were covered extensively in national and international press and discussed at the highest political levels. They also all led to improvements in the way the type of hazard is managed in the country concerned and in some cases internationally.

EXAMPLES OF DISRUPTION FROM UNPLANNED EVENTS

<table>
<thead>
<tr>
<th>TYPE OF HAZARD</th>
<th>EXAMPLE</th>
<th>IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme weather</td>
<td>Snow Storm in 2010, UK</td>
<td>• Traffic disruption</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Potential safety concern</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Economic costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Political repercussions</td>
</tr>
<tr>
<td></td>
<td>In 2010 a severe and unexpected snow storm caused the closure of several key routes in Scotland, including the M9, A80, A876 and the M8 between Glasgow and Edinburgh – some of Scotland's busiest roads. This led to thousands of motorists being stranded, having to abandon their vehicles, and leaving hundreds stranded overnight in freezing conditions, alongside causing congestion for a number of days along connecting routes. Around 300 fuel stations also reported shortages due to blocked routes to and from the Grangemouth refinery. Public transport (road and rail) also ground to a halt during this time. The economic impact of the storm is estimated to have cost the UK £1bn a day. The media reported that despite accurate forecasts prior to the event there was a lack of preparedness and no salt gritters were placed along these routes. Responding snowploughs reported breaking their blades because of thick ice. It was said that weak political leadership and a lack of coordination during the event exacerbated the impacts, leading to the resignation of the Scottish Transport Minister.</td>
<td></td>
</tr>
<tr>
<td>Infrastructure failure</td>
<td>Boston Manor Viaduct in 2012, UK</td>
<td>• Traffic disruption</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Potential safety issue</td>
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<tr>
<td></td>
<td></td>
<td>• Repair costs</td>
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<tr>
<td></td>
<td></td>
<td>• Reputational damage</td>
</tr>
<tr>
<td></td>
<td>In 2012 a major viaduct on the Olympic Route Network was found to have cracks in the concrete. The cracks were identified during a routine inspection and weight restrictions of 7.5 tonnes were imposed, diverting lorries and coaches onto local roads. There were concerns over it affecting coaches taking athletes from Heathrow airport to the Olympic Park. Repairs involved specialist steel plates being placed over the cracks.</td>
<td></td>
</tr>
<tr>
<td>TYPE OF HAZARD</td>
<td>EXAMPLE</td>
<td>IMPACT</td>
</tr>
<tr>
<td>------------------------</td>
<td>------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Extreme weather        | Hurricane Sandy in 2012, US                   | - Loss of life  
- Traffic disruption  
- Infrastructure damage  
- Economic impacts |
|                        | Hurricane Sandy was one of the most costly extreme weather events in US history, causing $70bn in damage and claiming hundreds of lives along its path. The 2012 event destroyed 650,000 homes, led to power outages for 8 million residents as substations flooded and falling trees struck power lines, flooded major cities, grounded more than 15,000 flights, submerged the New York subway system and shut down rail and road public transport operations, and led to the closure of major roads and bridges. The subway system was severely affected. Although it has pumping systems in place which remove rain and ground water the power outages prevented these pumps from working. In preparation for the storm the Metropolitan Transportation Authority moved buses and trains to higher ground, blocked subway entrances and ventilation grates, deployed pump and drainage crews, prepared emergency response vehicles and staffed their Incident Command Control Centre to coordinate and manage response activities. |
| Extreme weather        | Floods in 2014, Bosnia and Herzegovina        | - Loss of life  
- Costly infrastructure repairs  
- Traffic disruption  
- Economic impacts |
|                        | In May 2014 extreme rainfall triggered large scale flooding across Bosnia and Herzegovina, subsequently leading to over 3000 landslides, severely affecting 60 towns and cities. Landslides displaced many of the countries known minefields, and in combination with floods destroyed large areas of fertile agricultural land. The event and subsequent impacts claimed 62 lives and displaced hundreds of thousands of people. The events damaged 1262km of roads with repairs estimated to have cost €257m. This included damage to slopes and embankments, washing away carriageways, damage to bridge structures and tunnel lining, damage to drainage systems, and the destruction of traffic signs, markings and equipment. |
| Major transport hub    | Operation Stack in 2015, UK                   | - Widespread traffic disruption  
- Reputational damage |
| hub closed             | The management of freight traffic in Kent when there is cross-Channel disruption is referred to as Operation Stack. It consists of procedures developed in the late 1980s to deal with the traffic congestion that result from HGVs being unable to cross the channel at the port of Dover or the Eurotunnel. HGVs bound for the continent are parked along the M20 so that other national and local roads in the area are still able to operate. The coast bound M20 is closed and normal traffic is diverted onto other roads. Normally this procedure is expected to be in place occasionally for only short periods of time; however in 2015 Operation Stack was in place for over 30 days. The queuing system reached capacity adversely impacting on the surrounding roads. |
| Civil unrest           | Yellow vest protests in 2018, France          | - Loss of life  
- Widespread traffic disruption  
- Damage to infrastructure  
- Economic costs |
|                        | In mid-November 2018 ‘yellow vest’ protesters took to the streets to object to planned fuel price rises. Protesters caused significant damage to highway assets including vandalising 60 percent of France’s speed camera network and arson attacks on toll booths. Protesters also blocked highways which resulted in a number of collisions and deaths. The full extent of the disruptions caused to motorists is not yet known, however the cost of repairing highway assets is expected to be in the region of tens of millions of euros; the cost to the French economy is estimated to be billions of euros. |
| Infrastructure damage  | Morandi Bridge Collapse in 2018, Italy        | - Loss of life  
- Costly infrastructure repairs  
- Travel disruption  
- Economic impact |
|                        | In August 2018 a large section of the Italian Morandi Bridge collapsed into the Polcevera River and onto underlying railway tracks after a period of heavy rainfall, claiming the lives of 43 people. Demolition and reconstruction works began in early 2019 and are estimated to take 12-15 months to complete. The collapse impacted two key railway lines which took seven weeks to return to service and significantly affected the regional economy. |
Trends

Whilst new technology or mobility models emerging from the private sector can be beneficial, they can also be disruptive. It is not always easy to predict technology developments, how quickly they will be adopted and the impact they will have. For example Uber (the ride sharing and taxi booking company) was found to create additional traffic congestion in London, and Transport for London faced criticism for not foreseeing how quickly Uber would grow (London Assembly Transport Committee, 2018). Connected and Autonomous Vehicles (CAVs), electric vehicles, mobility as a service etc. all have the potential to impact road transport in the future. They also bring new vulnerabilities, such as the need for cyber-security.

Another important trend is climate change, which is expected to increase the frequency and magnitude of extreme weather events, cause sea level rise and changes in the timing of events such as snowfall. Whilst climate models provide an indication of the types of changes to be expected, there is still a high range of uncertainty in climate projections especially in the longer term. It is also unclear exactly how these climatic changes will impact on infrastructure. Many weather-related failures are complex, with multiple risk factors in addition to climate. More frequent extreme events can also mean there is less time for infrastructure owners to recover between events (see Figure 2).

"TfL needs to be prepared for the inevitable consequences of a transport environment in which technology is evolving faster than the legislation that is needed to govern its use."

Source: London Assembly Transport Committee (2014)
Potential levers for incentivising resilience
There are various levers that are available for different industry stakeholders to influence the resilience of road infrastructure. The use and effectiveness of these levers depends on:

- Who funds and manages the infrastructure
- The degree of autonomy that owners have
- The flexibility of industry standards and client specifications
- Availability or otherwise of alternative routes (i.e. competition)
- Ability of end users to influence decisions

Figure 3 depicts the key road stakeholders and the levers available to them to influence resilience. Although there are some similarities between countries/organisations, the available levers to incentivise resilience and the level of influence of different types of stakeholder depend on the organisational structure. There are large variations in the way transport infrastructure is managed between countries, transport modes, categories of road, regions within countries and different contract types. This results in differences in the available levers and the level of influence of different organisation types. This primer seeks to provide overarching insight and evaluation with specific examples of best practice from the interviewees from across different types of infrastructure management. Differences in organisational structures may mean that not every lever identified is applicable for all situations. It is also noted that some countries are going through major changes in the way their infrastructure is managed: e.g. from management by a government agency to private company (Germany) or from a centralised to regional structure (Norway). This presents both challenges and opportunities in terms of improving resilience.
The levers open to various stakeholder types are summarised below. Examples of the levers being employed in practice are given in Section 5.

GOVERNMENT AND REGULATORS

Government and regulators provide incentives for increasing road infrastructure resilience. In general national and state government oversee strategic roads, and municipalities are responsible for local roads, but the division of responsibility can be complex with multiple road authorities within one country.

Government often provides at least some proportion of funding for road construction and maintenance and set the overall performance requirements. The levers open to them for influencing resilience include:

- **Legislation and regulation** – how specific these are varies by country. In the US, changes to transport legislation needs to be approved by congress (this means transport requirements can become political, e.g. when referring to climate change). The UK Climate Change Act 2008 provides the power for the government to ask key organisations to report on their climate change adaptation activities. UK Civil Contingencies Act 2004 sets out duties of Category 1 and 2 responders. The Norwegian Planning and Building Act requires that risk and vulnerability assessments are carried out as part of the road planning process. In the US, the Fixing America’s Surface Transportation (FAST) Act requires resilience to be taken into account during transport planning.

- **Planning requirements** – Since 2014 in the EU Environmental Impact Assessments are required ‘to assess likely significant effects of a project on the environment, including vulnerability of the project to climate change and to major accidents and disasters’. Local planning authorities can also set planning requirements for new infrastructure which can include resilience. In the UK a number of National Policy Statements include aspects of resilience, e.g. Planning Policy Statement 25 on development and flood risk.

- **Licence or service level agreements** – Depending on the type of organisation infrastructure owners can have statutory requirements included in their licence or service level agreements (see National Infrastructure Commission, 2019). These help those working on improving resilience to convince colleagues for the need for action.

EXAMPLES OF ROAD ORGANISATIONAL STRUCTURES

Germany has federal roads, national and local roads. Currently the states (länders) manage the federal and national roads within their border, and the districts and municipalities manage the local roads. However, this is going to change in the near future, so that a private organisation manages the federal roads (BMVI, 2016).

Within the UK, transport is devolved to the four nations. In England strategic roads are managed by Highways England, a publicly owned company, and local authorities manage the local roads. However, within London, Transport for London manages major roads and the London Boroughs the local roads. In Scotland, Transport Scotland manages the strategic roads and the local authorities the local roads, and in Wales the Welsh Government manages the strategic roads and the local authorities. In Northern Ireland one organisation (a government department) manages all roads.
• **Performance indicators and metrics** – Performance targets may be agreed with government e.g. as part of a licence agreement or published metrics may highlight areas of poor performance affecting reputation (see National Infrastructure Commission, 2019).

• **Financial incentives** – Access to certain government funding sources can depend on actions to improve resilience (e.g. the local roads incentives fund in the UK described in Section 5).

• **Fines** – Infrastructure owners can be fined for not meeting performance targets by regulators.

• **Political pressure** – Government can ask questions either publicly in parliament, audits or expert reviews or at an individual level regarding resilience. This can impact on the infrastructure owner’s reputation if this is taken up by the media. Ministerial and public/media pressure are usually in reaction to a specific event. In Scotland in 2010 the transport minister resigned over comments on the response to heavy snow. This ultimately led to a number of changes to improve resilience (described in Section 5).

**CUSTOMERS**

Customers to some extent rely on government to represent their interest, but can also exert influence via:

• Social media, political representatives, customer surveys, user watchdogs, community groups and industry associations

• Not using toll roads

• Litigation if their legal rights have been violated

Customers can be influenced by educational campaigns, e.g. road users advised not to drive through floods or to take care when travelling through areas where there could be landslides and to take water with them during hot weather e.g. Highways England’s ‘Check before you travel’ campaign in 2018.

**OTHER STAKEHOLDERS**

Industry associations can influence resilience through:

• Code of practices (e.g. the UK Roads Liaison Group’s well-managed highway infrastructure) and industry guidance

• Awards and recognition for good practice

• Training and awareness raising

Organisations such as TRB, World Roads Association and the UK Infrastructure Operators Adaptation Forum can also influence awareness of issue and facilitate knowledge sharing.

• **Refusal to take ownership** (for the purposes of maintenance) of infrastructure built without taking resilience into account (an interviewee said they had done this).

• **Awards** – recognition of good practice by contractors.

**INFRASTRUCTURE OWNERS**

Infrastructure owners are influenced by Government and regulators, but also need to pass down requirements to their supply chain. They may also set their own policies and action plans regarding resilience. They influence suppliers via:

• **Design standards** – these may specify acceptable designs or be performance based

• **Procurement processes** – tender specifications, evaluation criteria and contract requirements for construction and term maintenance contractors.

• **Contractor performance indicators** – there may be financial penalties for not reaching these.
SUPPLIERS

Contractors can improve resilience as a result of a desire to be ahead of the competition and enhance their reputation.

Public-private partnerships (referred to as PPPs or 3P) are a slightly different case to traditional contact types, as the concessionaire not only designs and builds the road, but also has a long-term (e.g. 30 years) contract to maintain and operate it. This provides an additional incentive to ensure the constructed road is resilient as any future damage will increase the maintenance cost, and disruption will reduce revenue (which is normally linked to the number of users either through actual or virtual tolls). The concession agreement with the infrastructure owner will include performance requirements and KPIs, some of which may relate to resilience similarly to a traditional operation contract. This type of contract transfers some of the risk from the infrastructure owner to the private sector. However in some countries such as the UK and Sweden PPPs for road infrastructure have been banned by the government as they are not considered to be good value for money.

Private organisations also have a legal obligation to disclose risks to investors. A recent international initiative called the Task Force on Climate-related Financial Disclosures (TCFD) aims to increase transparency by encouraging companies to report on climate related risks. This includes both the impact of a changing climate on their business and also the effects of transitioning to a low carbon economy. This was not mentioned by any of the interviewees (which were representatives of infrastructure owners and government), however it may influence concessionaires as their investors are likely to require evidence that climate-related risks have been addressed.

THE ROLE OF DEVELOPMENT FUNDING

Whereas the majority of road infrastructure construction is funded by national government or through PPPs, in low and middle income countries (LMIC) external organisations such as the World Bank, European Bank of Reconstruction and Development (EBRD) and national aid agencies may provide development funding for road infrastructure construction. Many LMIC suffer from frequent natural and anthropogenic disasters and are less equipped to deal with them than higher income countries, due to lack of resources and less mature government structures. Dealing with these risks is part of development banks’ remits, and they have allocated funds to addressing these including specific funds to help countries adapt to climate change. Development banks have funded technical support to help develop institutional capacity to better deal with disasters and also wish to protect the investments they make in physical assets such as transport infrastructure. For example World Bank projects are now screened for climate and disaster risk and it has created tools to make this assessment more consistent (World Bank, 2019). Other development banks e.g. the African Development Bank, Asian Development Bank and EBRD are in the processes of introducing similar requirements. Loan agreements financing infrastructure construction may include requirements designed to limit future risks.
Rehabilitation of the Plumtree - Bulawayo - Harare - Mutare road (approximately 800 km), Zimbabwe. (© Arup)
Current resilience practices in the road industry
General overview of resilience penetration

Awareness of the concept of resilience within the road industry has increased enormously over the last six or so years. Prior to this, enhancing resilience was implicit in actions to improve infrastructure robustness and reduce delay, but it was less explicitly highlighted as an area of focus. Over the last few years, roles and teams explicitly established to address resilience have appeared within both infrastructure owners and policy makers. The term has also changed from being used mainly in terms of addressing terrorism to become a universal term relevant to all types of threat. Reference to ‘climate resilience’ in particular has grown over the past few years and there are now numerous road policies, organisational documents and research projects which highlight this topic. A quick search using a common research search engine for the terms transport and resilience shows the dramatic increase in use of the term since 2012 (Figure 4).

As recognition of the concept of resilience and its importance has grown, there has been a growth in actions to embed it in road decision-making. Actions which improve resilience may not always be recognised as such and may instead be understood in terms of reducing delay and the likelihood of infrastructure failure. Although these isolated actions contribute to resilience, a more thorough understanding of resilience and the need to address the system as a whole and consider the long term produces a more consistent and holistic approach to resilience.

The following sub-sections highlight how resilience has been addressed consciously in the different business areas of the industry. It is difficult to truly benchmark organisations as the infrastructure owners are unique; there are no direct comparisons for organisations such as Highways England for example, other countries have different infrastructure and organisational set-ups. However it is possible to identify areas where organisations have made some recent changes to improve resilience, and in many cases these are transferable to other organisations.
Strategic/organisational

Examples of levers to incentivise resilience at a strategic or organisational level include:

**HIGH LEVEL ACCOUNTABILITY FOR RESILIENCE**

Road infrastructure is mainly owned by the public sector (even privately owned roads are often PPPs or long term leases with some degree of government oversight). Therefore there needs to be high level government accountability. For example the Deputy First Minister is responsible for resilience in Scotland. Government has several avenues open to it to ask questions regarding road resilience.

**EXAMPLES OF GOVERNMENT OVERSIGHT FROM THE UK**

- In summer 2018, an Environmental Audit Committee questioned senior staff from Highways England on its response to heatwaves.
- The UK Climate Change Act 2008 gives the Secretary of State the power to direct reporting authorities (bodies with ‘functions of a public nature’ and ‘statutory undertakers’ which includes road organisations) to produce reports on what they are doing to adapt to climate change.
- In 2014 there was a government review of transport resilience (the Brown Review) (Department for Transport, 2014).

**EXAMPLE OF HIGH LEVEL RESILIENCE TARGET FROM THE NETHERLANDS**

The Dutch Government has set a target in the Delta Programme for the country to become climate resilient by 2050. This means having the right policies in place by 2020 and then making sure critical infrastructure is less vulnerable to climate change. Both Rijkswaterstaat (national roads), and provinces and municipalities (local roads) need to take this target into account. The Delta Programme was originally focused on flood management, but from 2018 has been expanded to include climate resilience in spatial planning. This expansion includes the MIRT (Multi-year Programme for Infrastructure, spatial planning and Transport); a series of collaborative projects on improving the physical environment, for example by adaptive planning.

Reputation was cited by many of the interviewees as one of the most powerful drivers for improving resilience, and having to answer to government (especially publicly) is an important incentive especially for public sector organisations. Therefore government stakeholders have a key role to play in terms of challenging decisions.

**EXAMPLE OF LEGISLATION TO ENSURE CONSIDERATION OF LONG TERM ISSUES**

The Well-being of Future Generations Act 2015 in Wales makes it a legal requirement for public bodies to consider the long-term and wider impacts of development. There are well-being goals which need to be considered and one of these is resilience. Compliance is overseen by a commissioner that can publicly name those which fail to comply and provide recommendations for improvement.
Nobody wants to be told they’re doing badly or not doing what they set out to do. This is the biggest incentive.

Source: Anonymous

INCLUSION OF RESILIENCE IN LICENCE/SERVICE AGREEMENTS
Resilience can be included in an infrastructure owner’s duties/role by including it in the legislation or licence agreement which establishes it as an organisation and sets out its statutory responsibilities. For example Highways England is directed by Government to consider long-term development and take account of future risks in its license. This clause helps those whose role is to improve resilience to demonstrate the imperative of taking action and to engage with others within the organisation. The monitor, the Office of Rail and Road (ORR), oversees compliance with licence conditions.

ORGANISATIONAL METRICS AND TARGETS
Organisational metrics and targets related to resilience can be set by governments to incentivise behaviour. There can be several metrics within a suite of measures which indirectly incentivise different aspects of resilience for example in terms of reducing travel delay, speed of dealing with incidents and taking action to increase the robustness of infrastructure. These proxy indicators do not fully encompass the true nature of resilience (particularly the long term aspects), but can be part of the approach to encouraging greater resilience.

Having a defined performance specification with defined targets for performance is good as you can see trends. Having a separate organisation that is looking at the trend and is challenging you, focuses attention and rightly so.

Source: Anonymous

HIGHWAYS ENGLAND’S LICENCE STATES THAT IT MUST:

Clause 5.6c: “Provide for sufficient flexibility and future-proofing in planning the long-term development and improvement of the network, taking account of long-term trends, uncertainties and risks - including new and emerging technologies and long-term trends in climate and weather conditions.”

Clause 5.4: “In complying with 4.2(b), the Licence holder should take all reasonable steps to ensure the continued availability and resilience of the network as a strategic artery for national traffic, and as an effective part of the wider road and transport system”.

Metrics focus an organisation on a particular aspect of performance and gathering the data to inform metrics can also reveal gaps in data and knowledge. This lack of asset information can impact resilience, for example a lack of knowledge of drainage condition can impede efforts to reduce flood risk. Therefore even if targets cannot be set, the very act of measuring different performance aspects, monitoring trends and publishing this information can incentivise behaviour.

The introduction of a set of performance indicators has had an impact. Looking at the metric on incident clearance time – how long it takes to clear incidents on the network - the trend of performance has been to see improved times, the company is prioritising the metric and its understood that it is important so weight is being given to it.

Source: Anonymous

EXAMPLE OF PERFORMANCE METRICS

The road investment strategy performance specification (DfT, 2014) sets out a number of performance measures (key performance indicators and performance indicators) for Highways England. Several of these relate to different aspects of resilience such as:

- The percentage of motorway incidents cleared within one hour. The target is 85% between 06:00 and 22:00.
- Average delay per vehicle
- Number of flooding hotspots and priority culverts mitigated (priority culverts are those considered to be undersized)

The performance measurements were agreed by the UK Department for Transport, Highways England and Office of Road and Rail (ORR) through a collaborative exercise involving specialists in different areas. The regulator ORR reviews Highways England’s performance annually. The results of the assessment are published, so in addition to the pressure exerted by government for not meeting targets performance also affects organisational reputation.

Other relevant documents include the vision and framework that accompany the metrics and include reference to Highways England’s duties as a Category 2 responder under the Civil Contingencies Act.
INTERNATIONAL STANDARDS AND GOOD PRACTICE

At an organisational level, obtaining international standards such as ISO 31000 risk management, ISO 55000 asset management and ISO 14001 environmental management can incentivise improvements to resilience, for example ISO 55000 advocates a risk-based approach to managing assets. There is also a new international standard ISO14090 ‘Adaptation to climate change - principles, requirements and guidelines’ being introduced in summer 2019.

In additional to reputation impact of obtaining these standards, the requirement to have them can also be stipulated by government. For example Highways England’s licence agreement requires asset management consistent with ISO 55000.

“As asset management translates the organisation’s objectives into asset-related decisions, plans and activities, using a risk based approach.”

Source: ISO 55000

In addition to the organisational international standards there are project specific national and international award schemes, for example CEEQUAL which require elements of resilience such as considering flood risk to achieve a high award level. These help to highlight good practice, proving an incentive in terms of enhancing reputation and helping to spread good practice.

ESTABLISHING DEDICATED RESOURCES FOR ENCOURAGING AND COORDINATING RESILIENCE ACTIONS

Several organisations including government departments have a dedicated person or team to encourage and coordinate its internal resilience actions and liaise with external parties in relation to resilience. This also helps to establish accountability and develop a chain of responsibility. For example the UK Department for Transport recently established a cross-modal resilience team which provides more focus on resilience across the organisation. These individuals are not the only people responsible for resilience within the organisation, but act as coordinators and drivers of resilience improvements.

These resilience champions can also be involved in multi-organisation dialogues for example as part of the Rhine alpine corridor group where there are transnational discussions between neighbouring countries and in European groups e.g. CEDR, ALICE (Alliance for Logistics Innovation through Collaboration in Europe). Benchmarking performance with other countries can create an incentive for improvement.

Road infrastructure has multiple interdependencies with other sectors including electricity, telecommunications, water/drainage and adjacent landowners. Resilience requires systems thinking and a geographic approach rather than focusing solely on one type of asset, which is in contrast to the division of responsibilities across different organisations.

Several countries have fora for cross-sector discussions on resilience including the Infrastructure Operators’ Adaptation Forum and local resilience fora in the UK and the National Hazard Forum in Norway. There are also transnational organisations such as CEDR (Conference of European Directors of roads) and PIARC (the World Roads Association) which have commissioned research on common challenges associate with resilience in the road industry.

“We’ve created a resilience team recently to give some special focus to that. It’s an opportunity to look at it properly and really spend some time on it.”

Source: Anonymous
USING RESEARCH, DATA AND TOOLS TO SUPPORT RESILIENCE

Many public sector organisations have been carrying out research to provide the data and tools to support efforts to improve resilience. For example the Federal Highway Association (FHWA) in the US has funded a number of pilot projects related to resilience and durability to extreme weather and the Delta Programme in the Netherlands is a government-led collaboration which is focused on flood prevention and climate proofing spatial planning. CEDR (Conference of European Directors of Roads), which is an association of European national road owners, has commissioned several projects related to climate resilience through its transnational research programme. Infrastructure owners have also commissioned their own research on resilience such as the Norwegian Public Roads Administration’s Climate and Transport research programme which fed into revisions to its manuals for design and practice.
Operational

Including resilience in operations is about prevention, preparedness, response and recovery. This is a cyclical processes and effective communication underpins all of these activities. Organisational responsibilities in relation to disaster/incident management may be set out in legislation (e.g. the duties of category 1 and 2 responders are defined in the UK Civil Contingencies Act), industry standards (e.g. Highways England’s Service Standards and Requirements of Service Providers) or individual contracts. There are also industry guidance documents that address these issues such as well-managed highway infrastructure (Roads Board, 2016). The following are examples of levers incentivising improved resilience in relation to road operations.

**PREVENTION**

There are a few direct drivers for carrying out preventative actions e.g. Highways England has a KPI related to upgrading priority culverts (Highways England, 2019). However most actions are driven by indirect incentives to reduce delay e.g. performance targets and reputation.

**PREPAREDNESS**

Some examples of preparedness are: establishing pre-determined diversion routes (UK and Germany) for the strategic road network which are agreed with the local authorities that own the diversion routes; setting up mutual aid agreements, for example for sharing salt supplies with other road authorities when they run low (UK); and preparing Disruption Risk Management Plans for different types of emergency (Scotland – see Figure 5). These have been mainly driven by government reviews following high profile events which made specific recommendations for improvements.

Part of preparedness is also ensuring that the right tools and resources are available during an event, for example access to real time data on weather. Norway has a web portal (xgeo.no) which provides current and historic weather conditions.

The portal Xgeo is also the basis for the national avalanche warning system, www.varsom.no. The portal is the result of collaboration between several state agencies. A network of observers report their observations on hazards such as floods or landslides via a mobile app (RegObs), including providing photographs. NPRA’s contractors are required to report their observations of natural hazards using an in-house communication system (ELRAPP) accessed via a mobile phone application. The data from ELRAPP also feeds into the Xgeo web portal.

Training of staff is also part of preparedness and there is a requirement for category 1 and 2 responders to take part in training exercises in the UK Civil Contingencies Act.

If forecasts suggest adverse weather conditions are likely, specific actions such as clearing drains, precautionary de-icing or restricting access of vulnerable vehicles to bridges can be carried out. Thresholds may be set to trigger certain actions; these can be included in operational contracts and/or communicated to users of the network. Early-warning systems can be used to warn users of risks, for example Transport Scotland has installed warning signs for travellers which are activated during periods of high landslide risk as a result of its landslide study (see Figure 6) (Winter et. al, 2005).
Figure 5
Transport Scotland’s trunk road and motorway operation contractor requirements for disruption risk management planning

Figure 6
Flashing warning signs for periods of higher landslide hazard and risk. Installation at the A83 Rest and be Thankful, Scotland (Winter et. al., 2017).
RESPONSE

During an event a common challenge is defining responsibilities or jurisdictions particularly between different organisations. Establishing clear roles and contacts beforehand is key. Examples of good practice from Transport Scotland include: formation of a multi-agency response team bringing together agencies and organisations that respond to events (planned and unplanned) on key transport links; establishment of a Resilience Room within the National Traffic Control Centre for liaison with government; communication with the public – clearer travel warnings e.g. Transport Scotland has four different advice stages depending on the severity of the weather; and use of technology such as variable message signs, social media to provide advice on travelling in snow, hot weather etc. Figure 7 shows how Transport Scotland sits within the emergency response structure.

Coordination between operational contractors and other road owners is specified in Highways England’s Network Management Manual, along with other winter service requirements such as record keeping, response and treatment times and contents of the Severe Weather Plan.

Key:
MART - Scottish Multi Agency Response team
SGoRR - Scottish Government Resilience Room
CSC - Cabinet Sub-Committee
S-PICC - Scottish Police Information and Co-ordination Centre
COBR - Cabinet Office Briefing Room
CCC - Civil Contingencies Committee
“The Service Provider must liaise closely with adjacent Highway Authorities and other service providers when designing Winter Service Route (WSR) to ensure consistency and continuity of winter service operations on all sections of the Network and with adjacent highway networks. The Service Provider must inform and keep informed adjacent Highway Authorities and other service providers of any changes to WSR.

Particular attention should be given to liaison with adjacent Highway Authorities for treating diversionary routes. If the diversionary route is outside of the Service Providers Network then the Service Provider is required to agree the treatment operation with the adjacent authorities.”

**RECOVERY**

Rapid recovery of routine events such as non-injury traffic accidents may be incentivised by target times for clearance. These are most often performance targets but in some countries can be legal obligations. Reputation and the impact on delay metrics also incentivise improvements to speed recovery.

Integrating the concept of ‘build back better’ i.e. increasing resilience to future events rather than replacing damaged infrastructure like for like is important. However, this may at times be in conflict with the need for speedy recovery. Sometimes, as a solution to this, temporary solutions are employed until permanent new infrastructure can be built.

**LESSONS LEARNED**

An important part of improving resilience is learning lessons from past incidents. This could be through use of a template or database which can be reviewed by others within the organisation, workshops for the parties involved in the event or government reviews. One way of capturing and spreading good practice is through industry awards and case studies.

Specialist equipment may be needed to clear the road after an accident.
EXAMPLE OF DATA MANAGEMENT DURING A DISASTER

In 2016 a 7.8 magnitude earthquake hit the south island of New Zealand. One of the most severe impacts was the damage to the transport infrastructure including key roads. This caused wide spread disruption affecting local communities, businesses and tourism. One key aspect in dealing with the aftermath of the event and carrying out recovering activities was data management. The stakeholders involved used a variety of approaches to manage and share data (Blake et. al, 2019):

- They used different types of existing data. This included using some types of existing data in novel ways e.g. vehicle telematics to monitor the use of alternative routes.
- New mechanisms were created for sharing data between organisations e.g. on damage assessments and cost estimates.
- Common classification systems were used to provide information on aspects such as levels of service.
- Existing and new relationships and communication channels were utilised. It was suggested that single points of contact within each organisation would help.

EXAMPLES OF INCENTIVISING RECORDING OF LESSONS LEARNED

**By providing a financial incentive**

The local highway maintenance incentive fund, set up by the UK government in 2014, allocates funding to English local highway authorities (outside London) according to their implementation of good practice. Each local authority completes a self-assessment questionnaire indicating if it is at level 1, 2 or 3 for 22 questions. Evidence is needed to justify the self-assigned level and DfT carries out random checks of the evidence. The overall score for all the questions determines the amount of funds the local authority receives.

One of the questions is “Does your local authority have a comprehensive approach to managing current and future risks associated with the highway infrastructure assets?” To score level 3 the local authority has to assert that their:

- “Approach to management of risk is continually improved and appetite to risk is clearly documented”
- “Lessons learned” around the management of risks are regularly recorded at all levels of the organisation
- “A documented approach to management of critical infrastructure on the network exists together with documented contingency plans.”

**By providing a contractual obligation**

Transport Scotland requires its operating contractors to submit post incident reports. The Performance Audit Group is audits compliance with contractual obligations.
Managing existing assets

Road asset management is about managing existing assets based on strategic goals using inventory and condition data. The major decisions in relation to asset management are what maintenance or upgrades to carry out in which location and at what time. The scale of work needed to build resilience is greater than the resources available; therefore the majority of these decisions focus on prioritisation of limited resources in order for infrastructure to be maintained to an acceptable condition. Roads in good condition are typically more resilient to hazards such as extreme weather.

**PRIORITISING MAINTENANCE**

Key to including resilience in asset management decisions is assessing risk in order to prioritise improvements to infrastructure to increase robustness to different types of threats. Risk includes both the likelihood of an event occurring and its impact, so identifying the most critical assets is an important part of this.

There are a number of risk assessment tools and methodologies which provide a systematic and consistent method of assessing risk, enabling infrastructure owners to focus on the areas of highest risk when planning maintenance, for example:

- **RIMAROCC** (Risk Management for Roads in a Changing Climate), a research project funded by CEDR, developed a methodology for assessing climate risk. This was refined and expanded in a later CEDR project ROADAPT (Roads for today adapted for tomorrow) and then used as the basis for the development of a software tool in DeTECToR (Decision-support tools for embedding climate change thinking on roads). The DeTECToR tool enables road authorities to map climate risk at a network level, now and in the future. It also enables the costs and benefits of different adaptation options to be compared.

- **The Norwegian Public Road Administration (NPRA)’s tool VegROS.** VegROS is the methodology used for the regular and obligatory risk assessment that is performed annually on all national roads. For other purposes, various other methods are in use. Initially the assessment focused on security and accidents, but it was updated to include natural hazards. Climate projections for 2050 are used in the analysis. The risk is scored based on the threat (probability of occurring and severity), adaptive capacity and importance of the road. High risk assets are analysed in more detail.

Apart from VegROS, the use of the other tools is voluntary and not integrated into organisational processes. However in the Netherlands, Rijkswaterstaat intends to carry out a network wide risk assessment for all climate hazards in 2019.

The NPRA has also initiated a project implementing a risk-based approach to asset management.
EXAMPLES OF INCENTIVISING THE PRIORITISATION OF MAINTENANCE ACCORDING TO CRITICALITY OR RISK

By offering an financial incentive

An example of incentivising road owners to prioritise their response is the UK Department for Transport’s local highways incentives fund (described earlier). One of the questions asked is “Has your local authority established a resilient network as recommended by the 2014 Transport Resilience Review?” The resilient network is a small part of the local authority network which it has identified as needing a high level of resilience, because it connects to essential services, major towns, ports or the strategic road network etc. Local authorities should prioritise this network when carrying out activities such as maintenance to improve condition, clearing drainage when heavy rain is forecast or responding to incidents.

By regulation

Another useful method of identifying areas of the network to focus on is to record historic events to highlight hotspots. An example of where this is incentivised is the ‘Periodic Evaluation of Facilities Repeatedly Requiring Repair and Reconstruction Due to Emergency Events’ regulation in the US. This regulation, effective since 2017, requires state department of transports to ‘determine if there are reasonable alternatives to roads, highways, and bridges which have required repair and reconstruction activities on two or more occasions due to emergency events’. Emergency events are those declared as emergencies by the Governor of the State or President.
MAINTENANCE CONTRACTOR REQUIREMENTS

A number of road owners have added requirements related to resilience into maintenance contracts.

NORWAY

NPRA develops preparedness plans for natural hazards for each contract area. The plans are based on a risk assessment carried out at the start of each term maintenance contract and are presented in the form of vulnerability maps (this is a separate, but related to the annual network-wide, risk assessment using VegROS). The NPRA goes through the risk assessment results with the area contractor to discuss how to deal with the high level risks. The preparedness plan includes information on the terrain, flood zones, hazard zones for landslides and avalanches, areas where snow drift is likely etc. The maps may include details of past events and existing protection measures. This ensures that information is passed on between the five to seven year contractual periods.

Operational contracts include the preventative operation and maintenance of the road network with respect to natural hazards and the requirement to report hazards via ELRAPP. Other contractor requirements include increased inspection frequency of culverts and requiring preventative maintenance when adverse weather is forecast. The NPRA provides training for contractors in regard to preparedness, climate change and tools for better risk management.

SCOTLAND

Since 2013/14, Transport Scotland contractors are required to use a Disruption Risk Management tool which identifies clusters of incidents on the network. The tool flags up sections of the network as red, amber or green according to the frequency and severity of incidents. Operating Companies are required to develop Disruption Risk Management Plans, which include wind/landslide/flooding/ winter plans, and diversion route plans which feed into the incident response plan. This is supported by thorough records of sites at risk, risk actions register and planning records. Transport Scotland also introduced manuals and guidance (Climate Change Adaptation and Resilience Plan, and Management of the Risk of Unplanned Network Disruption manual) to address disruptions, which include objective risk assessment tools to support planning and decision-making. Lessons learned from the 2010 event have led Transport Scotland to regularly refine their Operating Companies Contracts to include resilience requirements, such as clauses for proactive and reactive measures (including response and recovery times, initiating winter maintenance when temperatures fall below 5°C, requiring Operators to have suitable plant (such as ice breakers, ploughs), amongst many other measures.

"I think we need to place more requirements on contractors to have knowledge on resilience. Competency in this should be included in the tender specification."

Source: Gordana Petkovic, Norwegian Public Roads Administration:
Network upgrades

The main decisions for new assets are where and what to build. This consists of the initial business case for the new infrastructure, planning and appraisal processes, preliminary and detailed design and procurement of the construction work. Some road assets such as bridges have design lives of 100 to 150 years, so need to be designed for future conditions and with the ability to be adapted if required.

There are a number of methods used to embed resilience in new infrastructure.

**INCLUDING RESILIENCE IN THE STRATEGIC BUSINESS CASE**

A project proposal may include increasing the resilience of the transport system as one of its overall objectives at the start of a project. For example it could provide redundancy by providing an alternative route (e.g. a new river crossing), increase robustness (e.g. by replacing an old asset with a more robust design) or improve reliability by integrating measures such as raising the road height.

**INCLUDING A RISK ASSESSMENT IN THE PLANNING PROCESSES**

The location of infrastructure has a large influence on what type and level of threat it faces. Decisions on the optimal alignment needs to take into account multiple factors, but should consider the future resilience of the asset. Preliminary design decisions such as whether to use a tunnel or bridge to traverse a river also impact on future resilience.

**EXAMPLE OF INCLUDING INCREASED RESILIENCE AS AN OVERALL OBJECTIVE**

A proposed scheme to upgrade the A22 in Surrey, UK included the aim to increase resilience from the start (Surrey County Council, 2014). The road was damaged by flooding in February 2015, and the objectives were to repair the damage and to reduce the frequency of future flooding. The project included upgrading the water management system and improving traffic management facilities.

*Photo: Surrey floods in 2015, United Kingdom. (Photo by Phil John, Flickr.com)*
Examples of including resilience in planning include:

- Environmental Impact Assessment (EIA) is a common planning requirement used throughout the world, and in several countries it has been expanded to include a risk assessment (see Section 4).

- The consideration of risks, including climate change, at the planning stage of a project has been a requirement of the Norwegian Planning and Building Act for the past five to six years. The assessment is carried out by the road administration planners and engineers, and informs the road alignment.

- In the US the FAST (Fixing America’s Surface Transportation) Act 2015 requires that resilience is taken into account in transport planning. This includes recommending that infrastructure owners consult with agencies responsible for natural disaster risk reduction and the metropolitan transport plan assess investment to reduce the vulnerability of transport infrastructure to natural disaster.

- The UK National Policy Statement – National Networks “4.40 – New national networks infrastructure will be typically long-term investments which will need to remain operational over many decades, in the face of a changing climate. Consequently, applicants must consider the impacts of climate change when planning location, design, build and operation. Any accompanying environment statement should set out how the proposal will take account of the projected impacts of climate change.”

Planning legislation tells the industry it needs to assess risk, but not how to do this. Examples of the types of risk assessment tools infrastructure owners have used in road planning are the CEDR ROADAPT assessment and the Norwegian method for risk assessment.

The planning process also provides an opportunity for external input via the public consultation processes. Local planning authorities, statutory consultees and the public have a chance to raise any resilience concerns they have. For example in England the Environment Agency would highlight flood risk.

The planning processes includes social and economic appraisal of the design which needs to follow government guidance (e.g. WebTAG in the UK (Treasury, 2018)). The current version of webTAG does not explicitly include resilience in the economic calculations, but does mention some specific hazards (e.g. flooding) in the qualitative evaluation. The Treasury (UK) Green Book: Central Government Guidance on Appraisal and Evaluation includes supplementary guidance on including climate change in economic appraisal (Treasury, 2009). This discusses options such as real options analysis and adaptive planning.
Examples of Using Risk Assessment in Planning

InnovA58, The Netherlands

Rijkswaterstaat, the government agency that is part of the Ministry of Infrastructure and Water Management, and responsible for transportation and water infrastructure in the Netherlands, carried out a project on resilient and adaptive road infrastructure design. It applied the risk assessment methodology developed in the CEDR funded ROADAPT research project and the dynamic pathways approach to a planned road project in order to identify actions to improve its resilience and any wider lessons for the Dutch road network. The road project was the widening and major maintenance and refurbishment of a 50km section of the A58 highway. Rijkswaterstaat, the consultants Deltares and local stakeholders identified potential weather hazards and assessed the level of risk of these. The top five risks were assessed in more detail and potential solutions assessed for their effectiveness. The most viable solutions were plotted as dynamic pathways. The project concluded the combination of the two approaches was useful in designing more resilience infrastructure and highlighted the need for involving different local stakeholders and taking an area-based approach.

Risk Assessment, Norway

Risk assessment is a compulsory part of road planning in Norway (Norwegian Planning and Building Act) and is also included in the Norwegian Public Road Administration’s manual for impact assessment. Recent amendments have been made to ensure geology, hydrology and geotechnics are included. NPRA is developing a procedure for providing maps identifying hazards on the alignments being considered and rating the risk. There is a focus on cross-sectoral issues. The hazard maps developed during planning can follow the road project through to the operational phase.

New road projects are required to establish a storm water management plan. Drainage should be planned to cover a larger area and include alternative flood ways, retention ponds and protective ditches on slopes and cuts.
Figure 9
Example of a map identifying the hazards for alternative routes for the E39 road on the island of Stord, Norway (Petkovic et al., 2018)

- Agdestein tunnel (north side). Total risk = Medium
- Agdestein tunnel (south side). Total risk = Medium (green)
- Agdestein area (south of tunnel). Total risk = Medium
- Ankervika area. Total risk = Low
- Bortveit area. Total risk = Low (green)
- Bortveit area (north side). Total risk = Medium
- Agdesteinelva 2.9m
- Mehammerelva 2.3m
- Bortveitela 3.85m
- Gravaelva 3.09m
- Ådlandsvannet 5.3m (Frugardselva)
### INCLUDING RESILIENCE IN DESIGN STANDARDS AND SPECIFICATIONS

National, local and European (Eurocodes) design standards and individual project client specifications determine to a large extent what is built and to what standard. The review and updating of industry design standards is usually an ongoing cyclic process. There is always a balance between ensuring safety, durability etc. and affordability. Several infrastructure owners have recently reviewed and modified their standards to account for climate change, e.g. adding a climate factor when calculating drainage capacity requirements (as in the UK’s DMRB (Design Manual for Road and Bridges) and the Norwegian manual for road design). The need for revising the Eurocodes to incorporate climate change has also been acknowledged (European Commission, 2014), but not yet carried out. Infrastructure owners can include resilience in other organisational documents and guidance for their suppliers for example the ‘Road to Good Design’ (Highways England, 2018).

Incorporating increased resilience into design standards can be considered a better approach than including it in the specification of individual projects as it provides overall consistency and it is not possible for it to be cut due to budget restrictions as easily. Formal derogations may be required to depart from standards (although exceeding standards to make a design more resilient should not require this). The downside of modifying standards is that it can take a long time to change these with often multiple approval stages.

### INCLUSION OF RESILIENCE IN THE PROCUREMENT PROCESSES

Another method of including resilience in new assets is through the procurement process, i.e. client tender specifications, evaluation criteria, contract requirements, performance indicators and assurance of these. Most road infrastructure is constructed via build or design and build contracts, so for long term resilience to be considered in the design and construction, clients need to specifically request this. With design, build (finance) and operate (DBFO) contracts which are normally for 20 – 30 years there is greater incentive for contractors to build more resilient infrastructure which will require less maintenance in the medium term. This type of contract also transfers the risk related to future hazards to the private sector, although the performance requirements need to be well defined and managed.

> The promise of future work is a good incentive for performing well.

James Bailey, Chair of the UK Roads Board

### INCLUSION OF RESILIENCE IN FUNDING REQUIREMENTS

International development banks such as the World Bank and European Bank for Reconstruction and Development are starting to require consideration of resilience including climate change impacts in the projects they fund. This could take the form of a resilience audit at the early planning stage of a project and include requirements related to resilience to be included in the funding requirements.

> In the old days we had internal engineers with local knowledge, now we have new companies every 5-7 years and they do not necessarily have local knowledge of the roads. It is up to us to take care of this knowledge, document it and connect it to the requirements in the tender for maintenance and operation.”

Gordana Petkovic, Norwegian Public Roads Administration
Opportunities for achieving critical mass

Girardot-Puerto Salgar road construction, Colombia. (Photo by Arup)
In this section the information gathered from the interviewees and literature review is used as a basis for recommendations on incentivising resilience. Opportunities for increasing consideration of resilience have been divided into six areas for action as shown in Figure 10. Potential actions to address these areas are discussed in turn.

**Figure 10**
Areas for action to improve resilience
Changing mind-sets

Increasing resilience requires changing mind-sets in a number of ways:

**REINFORCING THE RIGHT BEHAVIOUR**

There is often more recognition for dramatic efforts to deal with and recover from events than for effective planning so that events do not occur. As one interviewee put it, people like to be a superhero. To counteract this, good practice in planning and preparation needs to be more widely recognised and rewarded, for example through case studies and industry awards. If it is possible to estimate the cost savings as a result of a preventative action or comparing an event where there was no/minimal impact with a similar historic event where there was impact this is a good way of demonstrating the value of resilience action taken.

**PROMOTING LONG-TERM THINKING**

When there are immediate problems to address finding the time and resources to consider the long-term can be difficult. This can lead to a reactive approach to managing disruptive events. An emphasis on reducing initial costs rather than considering whole life costs can also exacerbate this, favouring short-term solutions. Following good practice in asset management, by considering the infrastructure over its life cycle and identifying future risks will make an organisation more resilient.

*People like to be a superhero which is great. But you need to sustain energy and effort over the long haul.*

Source: John Lamb, President of the UK Local Government Technical Advisers Group
A good organisation thinks about all the possible things that can change the way they do things in the future. A weaker organisation would be one that envisages doing things in the same way they have always done forever.

Source: Anonymous

**BEING PROACTIVE WHEN CONSIDERING POTENTIAL HAZARDS**

Often it takes a disaster with large scale impacts such as public outcry, media attention, political ramifications or even deaths (as in the Morandi bridge failure) to trigger changes. When something catastrophic happens there is government money available to address that type of threat and a focus on instigating improvements. However, if repeat events do not occur within a relatively short timescale interest can wane and funding may dry up, sometimes before the identified improvements can be made. The inability to be certain what hazards infrastructure will face in the future and where these will occur can also be used as an excuse for inaction.

A more proactive approach where all potential hazards are considered and mitigation actions identified is more effective and less costly. This requires consistent long-term funding rather than funding that is only available for a short-time following a disaster.

**CHALLENGING CURRENT PRACTICES**

There is a tendency to become complacent when an event has not occurred for a period of time. People often follow what has always been done, rather than thinking of future considerations. There is also too much emphasis/trust on the ability of people on the ground to deal with anything that occurs rather than investing in better preparation and more robust infrastructure. Current practices need to be challenged and constantly questioned in order to be improved, for example through stress testing current practice with different scenarios and asking more customer-focused questions.

> If we ask the right questions in advance it would avert a lot of cost.

Source: John Lamb, President of the UK Local Government Technical Advisers Group
Providing leadership and accountability

Resilience has to compete with other priorities for resources and attention. Reducing the risk of travel disruption is less headline grabbing than, for example, the introduction of new types of vehicle technology or the construction of a new bridge. As one interviewee put it “resilience isn’t sexy”. Greater political and high-level organisational leadership on resilience could help to address this and provide powerful incentives to move resilience up the agenda. Some actions which can help to do this are:

**ASSIGNING A CHAMPION(S)**

There needs to be someone in a high-level position both politically and within infrastructure owner organisations to champion resilience and be accountable for improvements. For example a government minister responsible for resilience (as in Scotland), a coordinator of climate change adaptation (as in Sweden) or a cross-modal team responsible for transport resilience (as in the UK Department for Transport). There can also be cross-sector resilience champions such as the approach of appointing Chief Resilience Officers within city governments to embed resilience into all city departments including transport.

> I think it comes down to individuals showing leadership, people who understand that there is an expectation placed upon them and that they personally are required to undertake that leadership. If trained this can achieve great impact.

John Lamb, President of the Local Government Technical Advisers Group

**IMPROVING AWARENESS AND UNDERSTANDING OF RESILIENCE**

Whilst it is important to have someone accountable for resilience, there needs to be awareness and understanding of resilience throughout the organisation. Often outside the team involved in resilience, people do not understand what resilience is, why it is important or their role in improving it. Changes in staff or organisational structure can add to the problem, by leading to loss of knowledge and disruption of plans to improve resilience. Actions to increase awareness include providing workshops, guidance, case studies, role-specific training and including objectives in an individual’s appraisals. There are multiple sources of external case studies, but examples of good practice from within the organisation are particularly relatable.

For the individuals coordinating actions to increase resilience, high-level support and ‘hooks’ such as a clause in the licence agreement text or organisation metrics are useful in helping to get their points across to colleagues (see Section 5).

> It’s everyone’s job and everyone’s responsibility. It shouldn’t be about having 1 or 2 key people going on a course; it needs to be broader that allows more people to become generally well informed.

John Lamb, President of the Local Government Technical Advisers Group
DEMONSTRATING THAT RESILIENCE IS IMPORTANT

Leaders need to be visible in resilience discussions and actions in order to demonstrate the value they place on resilience. For example speaking at external and internal events on resilience, asking staff questions on resilience and being involved during events as during severe winter weather in Scotland.

We had the Transport Minister replying to tweets in the Control Centre until 1am in the morning. It's good to have the Government involved in high impact events.

Transport Scotland

Part of demonstrating the importance of resilience is having the evidence to support the need for greater resilience, particularly in terms of economic benefit. In order to engage people and support funding request it is necessary to set out the business case for measures to improve resilience. This requires including risks within economic appraisal, and setting appropriate boundary conditions.

ESTABLISHING POLICY, TARGETS AND ACTION PLANS

By including resilience in organisational/government policy and developing appropriate action plans, it demonstrates its importance internally and externally. It also allows people working on resilience within the organisation/industry to use this to engage their colleagues. Setting targets on resilience is difficult, although this has been done in the Netherlands (see Section 5.2). Definition of what the expected level of resilience/performance is which then allows resilience measures to be developed and put forward for funding would be useful, and will be different for different types of road. For example Transport Scotland stated that “by 2050, there will be less or no more disruption on the transport networks caused by flooding compared to 2010”.

Providing ring-fenced funding for resilience

Every road owner has a limited budget, and for local road owners especially a lack of resources can be seen as a barrier to increasing resilience. To address competing priorities and prevent focus on the short-term issues funding specifically for actions to improve resilience may be required. For example in Ireland specific funding was ring-fenced for drainage works to help promote increased network resilience of local roads (Construction Index, 2019).

Having assurance procedures in place

Often after an event recommendations to improve resilience are made, but there also needs to be a process in place to ensure these have been addressed. For example in 2012 there was a government review (DEFRA, 2012) of the implementation of the 92 recommendations of the Pitt Review of the 2007 flooding in the UK. This evaluated the progress in implementing the recommendations, explained which recommendations were not being taken forward and why and what work was still ongoing.
Systems thinking and collaboration

Resilience requires a cross-asset, cross-sector approach which involves collaboration between organisational business units and different organisations. Resilience needs to be addressed at the system level, rather than solely focusing on individual assets. There are opportunities to improve resilience through less siloed working and greater awareness of external interdependencies. Potential actions to encourage systems thinking and collaboration are:

**USING APPROPRIATE LANGUAGE AND ASKING THE RIGHT QUESTIONS**

One interviewee highlighted the importance of the language used when discussing resilience and the questions asked. This can encourage or limit systems thinking.

> **“I think it’s really important to recognise, when we talk about these things you’re actually constraining people’s imagination by the language you use and the questions you ask. I would like us to start thinking less about the individual asset, and more about the systems that they form part of and the functions that those systems fulfil.”**

Source: Anonymous

**FORMING DISCUSSION FORUMS**

Regular resilience forums and resilience champions/coordinators can help bring staff from different business units and/or organisations together to discuss resilience of the system as a whole, for example the Natural Hazard Forum in Norway.

**ESTABLISHING MULTI-AGENCY RESPONSE TEAMS**

Multi-agency response teams, plans and training for different types of threats can also help organisations work together so that there is no miscommunication. There needs to be coordination between different infrastructure owners e.g. strategic and local roads, and roads and rail. For example, Transport Scotland setup a Multi-Agency Response Control Centre, which brings together key partners from Transport Scotland, the Met Office, ScotRail, Operating Companies and Police Scotland. The control centre is staffed 24/7 and acts to share real-time accurate information with key stakeholders, issues advanced travel warning to logistics networks and the travelling public, and coordinates emergency response. The control centre not only allows event coordination, but also enables knowledge sharing and collaboration between all key stakeholders.
Understanding and mitigating risk

In order to prioritise maintenance and upgrades to improve resilience, identification of the areas of highest risk is required. Data collection and analysis is required to support hazard and risk assessments, and decision-support tools and standardised methodologies provide a consistent methodology so that comparisons can be made between projects, areas of the network and hazards.

The requirement to carry out a risk assessment can be embedded in the planning process for new build and asset management processes for existing networks. It should be reviewed regularly and the information passed to each new contractor that takes over the operation of that section of the network and appropriate requirements embedded within the contract, as is being introduced for national roads in Norway.

To make risk assessment more consistent and evidence-based, methodologies and tools are being developed by road authorities, such as the FHWA vulnerable assessment scoring tool that assesses exposure, sensitivity and adaptive capacity. Other useful approaches to inform decision making are dynamic adaptive pathways and stress testing. It is important that decisions on resilience are based on robust research and evidence.

“We are moving more towards evidence based processes and away from the past when we had less science available.”

Source: Anonymous

Route 2 following extensive repairs to a large slope failure area. The road was closed for six miles in western Massachusetts following Tropical Storm Irene. Before (left) and after (right) repairs.
Improving disaster management

Preparation for different types of events should include plans to deal with disruption, contingency plans and recovery plans. These need to set out the responsibilities clearly and be supported with sufficient resources and training of staff. Agreements of mutual aid for example and multi-agency practice events are helpful. Plans should include how to share information and data, before, during and after an event (see the New Zealand example in Section 5). There also needs to be a debrief after events to identify lessons learned.
Embedding resilience

No single lever can embed resilience within the road industry. There needs to be inclusion of multiple specific actions to support resilience integrated in existing procedures at all major decision points and involving all industry stakeholders.

For example government and regulators need to:
- include clauses relating to resilience in licence/service agreements
- develop supporting metrics/ targets
- and use their influence through asking the right questions both publicly and in private.

Infrastructure owners need to:
- include an assessment of future risks to the infrastructure in their construction projects and asset management policies,
- improve response to events; and
- incentivise their supply chain through contract requirements.

Other organisations such as local planning authorities, contractors, customer watchdogs and professional initiatives also have roles to play in highlighting areas for improvement and influencing the industry. As several interviewees highlighted it is the application of all these levers together which are important.

“All of these things together align and give a consistent message and make clear the expectations.”

Source: James Bailey, Chair of the UK Roads Board

The supply chain has to adhere to the standards that we set when they are designing road projects (unless they have a departure). So that has a major influence on the way projects progress. But the Strategy, for instance, affects lots of other areas (procurement) so there are other strands of influence. Also, another thing that shapes projects is we have a Project Control Framework which sets the outlines of how projects should progress from start to finish. Within that there are various stages that allude to good design, environmental assessment process has to be gone through, and we have an EIA directive that has climate resilience in it. So there are a number of levers that are operating on the supply chain.

Source: Anonymous
Conclusion

The interviews carried out as part of this project have provided useful insights into the challenges practitioners and policy makers in the road industry face in embedding resilience within their organisations and the industry. This primer highlights examples of good practice, and provides recommendations on potential actions to increase resilience. Resilience is an increasingly important issue and learning from each other’s experiences is vital in order to keep making progress.

We hope these recommendations will contribute to the current thinking within the roads sector around how to embed resilience, and how to motivate its implementation from theory into practice.
ABOUT THE AUTHORS

TRL are delighted to be involved in the Resilience Shift initiative, which very much aligns with the work we are carrying out in the UK and internationally on resilience. Resilient road transport underpins a successful society and we are very pleased to be able to contribute to highlighting the need for resilience and the types of actions that can be taken to incentivise it.

The following researchers were involved in developing the primer:

**Dr. Sarah Reeves** is a Senior Consultant, with 16 years’ experience of working on road and rail resilience and climate change adaptation. She is a member of the World Roads Association Technical Committee on climate change adaptation strategies and resilience. Her experience includes the use of climate projections to assess the risks of climate change impacts on transport, the development of risk assessment and management strategies, national and international policy analysis, the embedment of resilience and the provision of recommendations on adaptation actions.

**Prof. Mike Winter** is a Chartered Civil Engineer and a Chartered Geologist. He is the Regional Manager responsible for TRL’s infrastructure operations in Scotland and a visiting industrial Professor of Engineering Geology and Geotechnics at the University of Portsmouth. During the last 28 years he has acquired broad experience in research and specialist consultancy. His main area of expertise is in landslides; their forensic investigation, management and mitigation and the wider socio-economic impacts they cause.

**Dominic Leal** is a Researcher with 3 years’ experience. He has a BEng (hons) in Civil Engineering and MSc in Sustainable Development. His experience includes assessing the impact of new technologies such as Electric Road Systems on the road industry.

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References

ENDNOTES

1. The Federal Highway Research Institute (Bundesanstalt für Straßenwesen) is a government road research organisation which provides the German Federal Ministry of Transport and Digital Infrastructure with technical advice and support.


3. The Act divides responders into Category 1 which are the major responders to emergencies such as police and local authorities, and Category 2 which are cooperating bodies. The duties of the two categories are different.


OTHER REFERENCES


