FEHRL

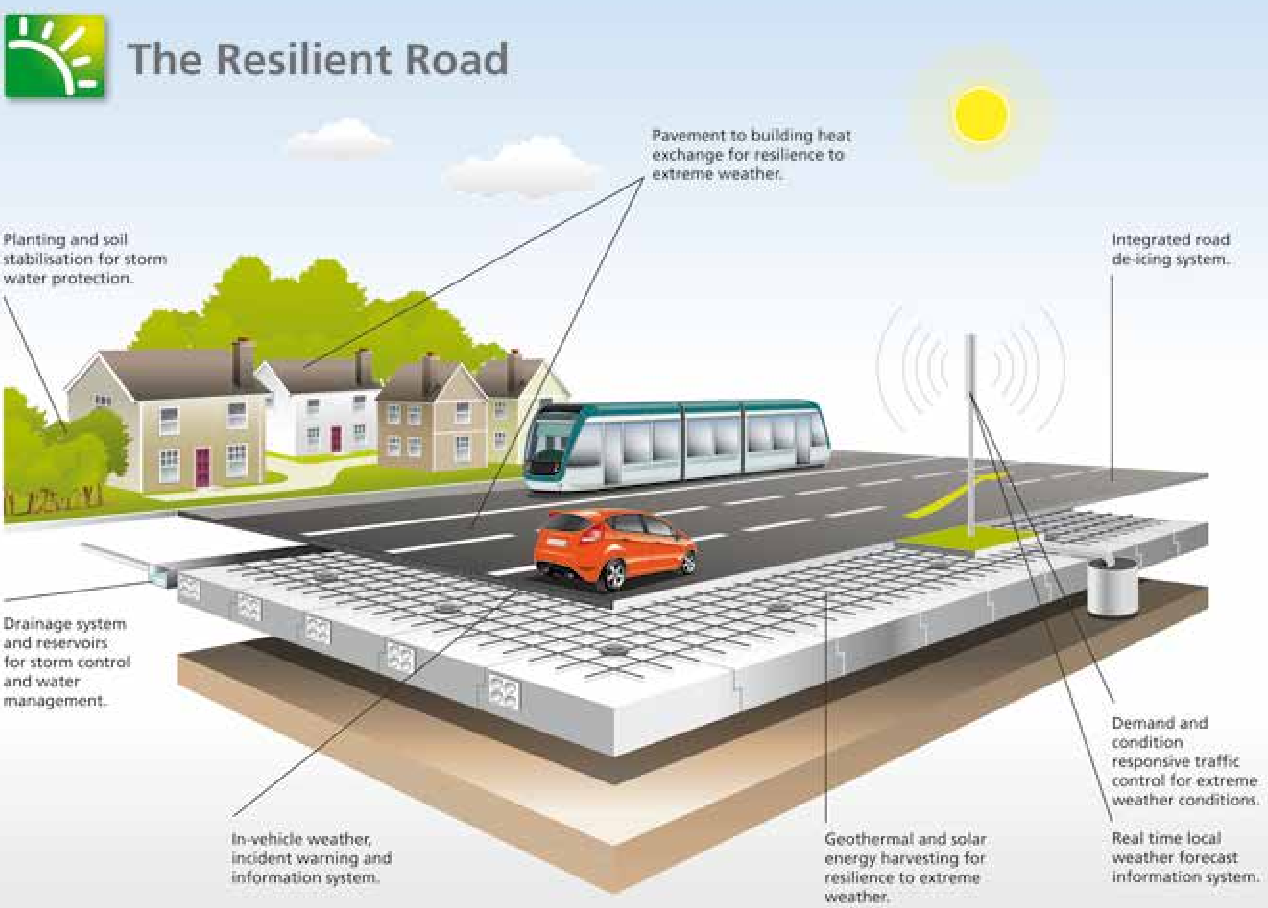
THE RESILIENT ROAD

A ROADMAP FOR RESEARCH

AN ELEMENT OF THE FOREVER OPEN ROAD

JANUARY 2013

FOREVER OPEN ROAD
Redefining Road Transport for the 21st Century
FEHRL's Flagship Programme



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EXECUTIVE SUMMARY

The Forum of European Highway Research Laboratories (FEHRL) has initiated the Forever Open Road Programme as the core of its Strategic European Road Research Programme V (SERRP V). The Forever Open Road Programme works towards a next generation of advanced and affordable roads that can be adopted both for maintaining the existing network and building new roads. This will enable future road operators to adopt emerging innovations, whilst overcoming the increasing constraints on capacity, sustainability, reliability and integration. Forever Open Road will also contribute substantially to the way the road transport sector addresses societal challenges.

The next generation of roads will require high levels of adaptation, automation and resilience. These three elements will define the next generation of road as follows:

- **The Adaptable Road:** focusing on ways to allow road operators to respond in a flexible manner to changes in road users demands and constraints
- **The Automated Road:** focusing on the full integration of intelligent communication technology applications between the user, the vehicle, traffic management services and the road operations
- **The Resilient Road:** focusing on ensuring service levels are maintained under extreme weather conditions

This Roadmap describes the Resilient Road Element of the Forever Open Road Programme. The Resilient Road Roadmap has been developed through a series of workshops with technical input from experts and practitioners from FEHRL and supporting organisations.

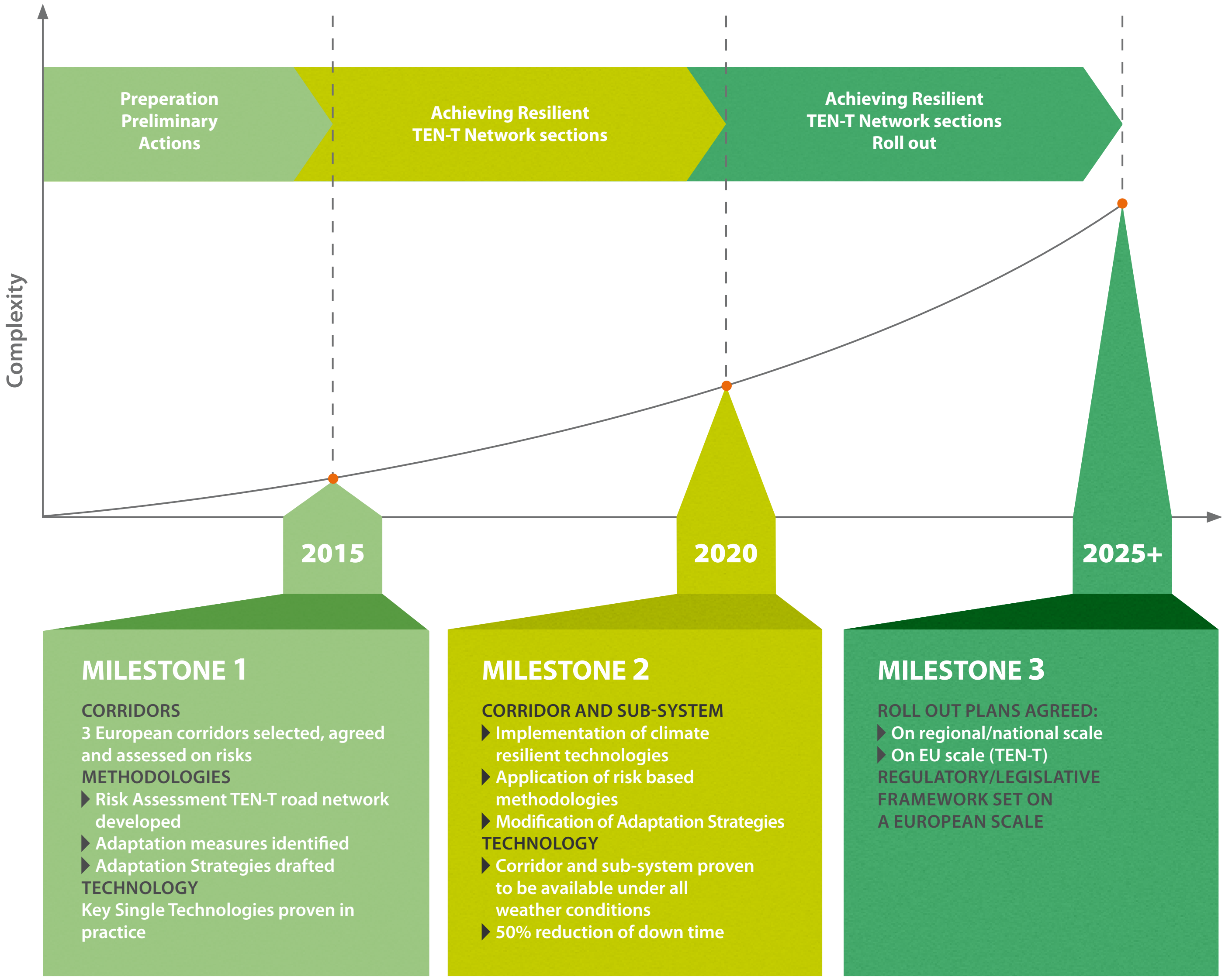
An efficient and reliable transport system is essential for the society, for the transport of goods, for employment and for leisure. Currently, Europe's transport systems struggle to cope with extreme weather events such as droughts, heavy rain and snow, storms and floods; and climate change is predicted to increase the frequency and severity of extreme weather events.

The entire transport infrastructure (road, rail, sea ports and inland waterways) will be significantly impacted by climate change, affecting the way Europe's transportation sector plans, designs, constructs and maintains infrastructure in the future.

On the basis that there will be significant impacts from climate change, and considering that all eventualities cannot be catered for, this Roadmap aims to determine how road transport infrastructure should adapt to the inevitable changes, increasing resilience to the potential effects of climate.

This Roadmap sets out the steps required to maintain and improve the resilience to extreme weather of road transport networks and specifically the key Trans-European Network (TEN-T) road transport network events. Whilst focussing on roads, it will also consider interactions with other modes (rail and inland waterways).

The figure (on the next page) outlines the key milestones that have been proposed.



The guiding principles of the Forever Open Road Resilient Element are that:

- A reliable transport system is essential to the functioning European society
- The financial cost of network interruption from extreme weather events is difficult to quantify, but is estimated to be in excess of €15 billion
- Climate change will increase the severity and frequency of extreme weather events and thereby lower the reliability of the transport system
- Given the long life cycle time of infrastructure, action is needed urgently
- The following headline actions are proposed:
  - Define requirements for climate projections
  - Support the harmonisation of climatologic data
  - Identify vulnerabilities on the key European transport networks
  - Identify key high risk points on the network
  - Establish future service levels for the TEN-T road network
  - Identify technologies for climate change adaptation
  - Investigate processes for cost-effective adaptation
  - Establish field operational trials (FOTs) of integrated adaptation measures, in conjunction with other elements of Forever Open Road
- The required R&D funding to achieve a European climate change resilient transport network will initially be relatively low, but will increase significantly once full scale FOTs are under construction.

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1. INTRODUCTION

1.1 FOREVER OPEN ROAD PROGRAMME

The Forum of European Highway Research Laboratories (FEHRL) has initiated the Forever Open Road Programme as the core of its Strategic European Road Research Programme V (SERRP V)[1]. The Forever Open Road Programme works towards developing a next generation of advanced and affordable roads that can be adopted both for maintaining the existing network and building new roads. This will enable future road operators to adopt emerging innovation, whilst overcoming the increasing constraints on capacity, sustainability, reliability and integration. The overall aim is to facilitate the future mobility needs of our 21st century society.

The next generation of roads will require high levels of adaptation, automation and resilience. These three elements will define the next generation of road as follows:

- **The Adaptable Road:** focusing on ways to allow road operators to respond in a flexible manner to changes in road users demands and constraints
- **The Automated Road:** focusing on the full integration of intelligent communication technology applications between the user, the vehicle, traffic management services and the road operations
- **The Resilient Road:** focusing on ensuring service levels are maintained under extreme weather conditions

This Roadmap describes the Resilient Road Element of the Forever Open Road Programme. The Resilient Road Roadmap has been developed through a series of workshops and technical input from experts and practitioners from FEHRL and supporting organisations. Annex 1 details the participants and their roles in developing this document.

1.2 THE RESILIENT ROAD ELEMENT

The Resilient Road Element is aimed at ensuring that the road network remains open under extreme weather conditions. Within this element, innovation themes will address the adaptation of road operations and management of the effects of extreme weather (flooding, snow, ice, storm, drought, heat) to such an extent that adequate service levels are ensured. Innovation technology will be key to the development of resilient solutions that can overcome the challenge of ensuring availability; these include improved materials, soil strengthening and rock stabilisation, improved water management, early warning systems based on local weather forecasts, and dedicated weather proofing systems.

1.3 SOCIETAL CHALLENGES

The Forever Open Road Programme will contribute substantially to the way the road transport sector addresses societal challenges[2]. Table 1 shows the Indicators and Guiding Objectives that Forever Open Road will help to address, specifically in meeting the challenges of decarbonisation, reliability, safety & security, liveability and costs.

[1] Strategic European Road Research Programme (SERRP V), 2011 – 2016, FEHRL (see http://www.fehrl.org/?m=18 for more details).
[2] ERTRAC Strategic Research Agenda 2010: Towards a 50% more efficient road transport system by 2030

Societal challenge	Indicator	Guiding objective	Adaptable	Automated	Resilient
Decarbonisation	Energy-efficiency of passenger and freight transport (in kWh)	+10%-20%*	moderate	moderate	strong
	Energy consumed by road operations	Net zero	moderate	moderate	moderate
	Energy embodied in materials	-25%*	moderate	insignificant	moderate
Reliability	Failure frequency and duration	-35%*	moderate	moderate	moderate
	Time lost to maintenance, repair, reconstruction and incidents	-50%*	moderate	strong	moderate
Safety & Security	Fatalities and severely injured	-35%*	moderate	moderate	strong
	Goods lost to theft and damage	-40%*	strong	moderate	strong
Liveability	Air quality, noise, natural habitat	Policy compiliance	moderate	moderate	strong
Cost	Total cost of ownership	-30%*	moderate	moderate	moderate

*** vs a best practice baseline** **● a strong contribution** **● a moderate contribution** **○ insignificant contribution**

Table 1: Societal challenges to be addressed by the Forever Open Road Programme (source: SERRP V programme)

The Resilient Road contributes to all of these objectives by increasing the resilience of the road network to the effects of climate change and extreme weather events as outlined in the text below.

Decarbonisation > The Resilient Road is expected to help decarbonisation by reducing traffic delays and the need for the lengthy re-routing of traffic. In addition, the design and construction of low embodied energy infrastructure elements that are suitable for the climatic conditions in which they are situated will help decarbonisation and improve resilience. This, in turn, promotes resource efficiency and the reduction in maintenance activities.

Reliability > Adaptation of the road network to extreme weather events will increase the reliability and availability of the road network by keeping it open during extreme weather events.

Safety and Security > The Resilient Road has a role to play in ensuring safety, in that whilst improving the reliability and availability, it will ensure adequate safety levels, e.g. skid resistance is maintained. Improvements in drainage and a reduction in surface water from storm events would be examples where safety can be improved. Ensuring reliable operation in all weather conditions will help improve freight security.

Liveability > Strong interactions between the Resilient and Adaptable Road Elements will ensure the design of a road with low noise, low emissions and protection of the natural habitat. Many of the elements related to ensuring operation in extreme weather such as porous asphalt will also aid in noise reduction, whilst prevention of flooding and a holistic overview of transport and land planning will minimise the impact of the road on the natural habitat in which it sits.

Cost reductions > Cost reductions will arise from:

- Increased network availability and reduced delays to traffic;
- Lower time lost to maintenance and repair activities;
- Longer lasting infrastructure elements that are appropriate to their climatic conditions, giving an overall lower whole life cost.

2. EXTERNAL DRIVERS FOR THE RESILIENT ROAD

2.1 CHANGING CLIMATIC CONDITIONS

Safe and efficient transport systems are essential to the functioning of business and society; the disruption caused by extreme weather events such as snow, flooding or heat are evident, and have implications for all travel modes. The economic costs of current extreme weather events are significant, even for relatively limited losses of availability. It is reported that extreme weather conditions cost the EU's transport system at least €15 billion annually[3].

On the basis that there will be significant impact from climate change, this Roadmap aims to determine how road transport infrastructure shall adapt to the inevitable changes, i.e. the Roadmap is concerned only with adapting the infrastructure (increasing the resilience) to the potential effects of climate, not with the mitigation of climate change, such as efforts to reduce carbon emissions by, for example, electric vehicles. Whilst such mitigation efforts will be facilitated by the Adaptable Road Element of Forever Open Road, this Roadmap and the Forever Open Road Programme is exclusively focused on the transport infrastructure itself.

Climate change can manifest itself by gradual changes in climate parameters which, unlike extreme weather events, can go unnoticed yet still have an effect on the durability and functioning of road infrastructure; examples include steady increases in temperature and ultraviolet (UV) exposure, a rise in sea level and changes in groundwater levels. There may be a requirement for countries to adapt their design standards and maintenance regimes accordingly. It is likely, however, that the main effects will not be related to, for example, a mean increase in temperature of 2o centigrade or an increase in annual precipitation of 10%, but rather an increase in the number of days per year that the temperature exceeds a threshold that can cause damage to asphalt, or an increased occurrence of extreme rainfall events.

It should also be recognised that some effects might be positive, for example lower winter maintenance requirements in some areas and reduced winter damage. It is also worth considering the variability in weather as an interaction with climate change; for example, the potential of a severe winter in the coming decades such as experienced in much of Europe during 2010/2011. For road owners and operators, it is important to understand the potential future climate in order to respond accordingly.

Some uncertainty exists about the potential impacts that climate change may cause, not least because of uncertainty as to the international response in reducing greenhouse gas (GHG) emissions (mitigation). The purpose of this Roadmap is not to go into the scientific details of climate change, but to examine what potential impacts there might be, what impact that might have on the transport infrastructure, and what adaptation measures might be required. The predicted impacts and resulting vulnerabilities are considered below.

2.2 CLIMATE CHANGE FORECASTS

Forecast temperature and rainfall patterns across Europe are presented below, showing a general increase in temperature across Europe, but particularly in the far south Mediterranean areas, in eastern and the far north of Europe and in mountainous regions. This generally corresponds to a decrease in precipitation in southern Europe and an increase in northern Europe, although this is unlikely to be uniform. Even in areas that appear to show little change, such as the United Kingdom and northern France, whilst annual precipitation might be broadly similar, it is predicted that summers will be drier, whilst the winters wetter. There will also be more intense rainfall events.

[3] EWENT, http://www.vtt.fi/inf/pdf/technology/2012/T36.pdf

Temperature: change in mean annual temperature [C°] **Precipitation: change in mean annual amount [%]**

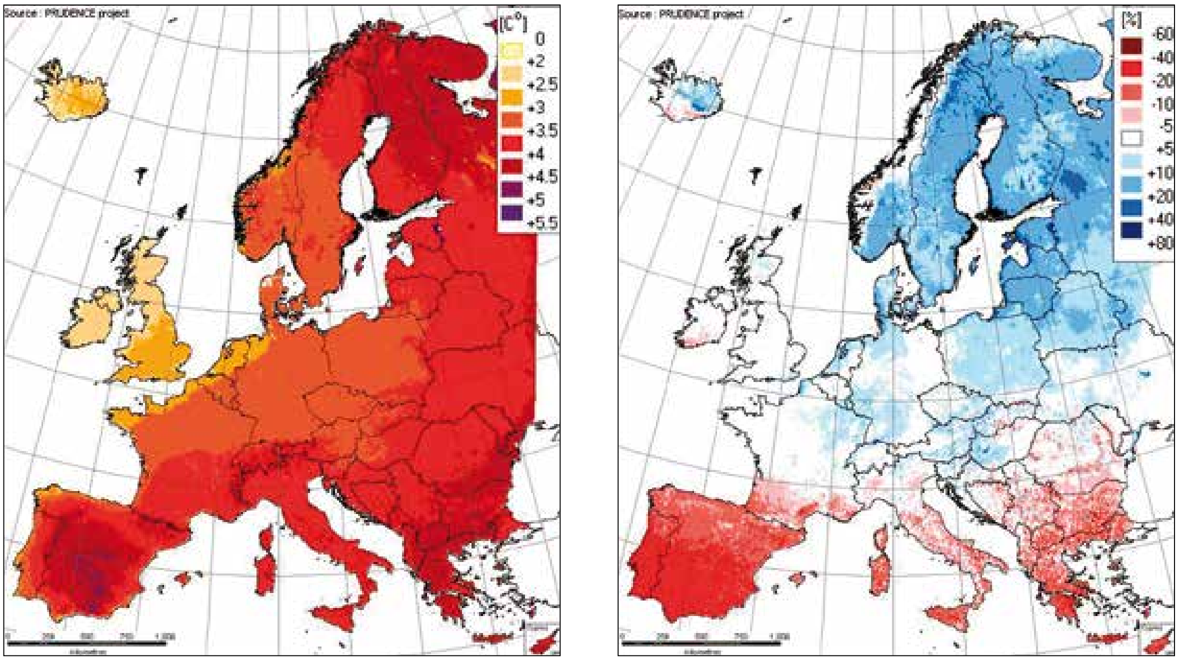


Figure 1: Change in mean annual temperature[4] (left) and mean annual precipitation[5] (right) by the end of this century (taken from http://peseta.jrc.ec.europa.eu/docs/ClimateModel.html)

As the climate changes, extreme weather events may become more frequent, more intense and longer lasting. Vulnerability to climate change varies widely across regions:

- In low lying countries with islands and extensive coastlines such as Denmark[6]; sea level rise has affected land drainage, causing groundwater to reach the surface temporarily or permanently, causing 'blue spots' triggering road closures
- The Mediterranean area is becoming drier, making it more vulnerable to drought and wildfires, whilst Northern Europe is getting significantly wetter, and winter floods could become common
- Europe's far south, east and the Arctic show significantly increased temperatures, as do the Alps. In addition to changes in general precipitation, there could be changes to the proportion falling as snow or rain, changes in the melting of snow and ice, and in the freeze-thaw patterns

2.3 POTENTIAL IMPACTS OF CHANGING CLIMATE ON TRANSPORT INFRASTRUCTURE

Whilst there will be various changes across the geographic areas of Europe, some of the risks to the highway network are outlined below:

- Flooding either through precipitation or potentially rapid snow/ice melt in some regions and some of the associated effects such as:
  - Operational disruption, reduced network availability and blockages
  - Bridge scour, inundation of tunnels and landslides
  - Saturation of the unbound layers, resulting in loss of fine material, settlement and failure
  - Saturation of the subgrade causing a reduction in strength
- Hotter, drier summers leading to a reduction in sub-surface water, causing shrinkage of the sub-surface and inducing cracking. Increasing changes in sub-surface water can cause soil to shrink and expand significantly, causing the overlying pavement layers to heave and subside

[4] Absolute change in mean annual temperature between control period 1961-1990 and 2071-2100, under the IPCC SRES scenario A2. Data from EC-funded project Prudence (HadCM3 global circulation model, and HIRHAM regional climate model in 12km resolution), map elaboration by EC JRC/IES.

[5] Relative change in mean annual precipitation between control period 1961-1990 and 2071-2100, under the IPCC SRES scenario A2. Data from EC-funded project Prudence (HadCM3 global circulation model, and HIRHAM regional climate model in 12km resolution), map elaboration by EC JRC/IES.

[6] Kristiansen, J R: 2010. Rising groundwater levels can cause permanent flooding of roads. Transport Research Arena Europe. Brussels.

- In periods of hot weather, asphalt surface layers can become susceptible to rutting and deformation. In addition, high temperatures can make newly laid asphalt remain workable for an extended time, making it difficult to maintain profile during compaction
- Thermal gradients can create uneven internal stresses, giving rise to curling or warping in concrete pavements
- Reduction in vegetation due to higher temperatures and drought, and/or higher wind speeds could increase erosion processes on embankments, leading to them becoming unstable
- Intense rainfall events causing erosion or landslips/landslides on embankments. Extreme rainfall events in areas with reduced vegetation, described above, would intensify erosion
- A milder climate could have implications for northern areas of Europe where the ground is currently frozen during winter, through increases in the freeze-thaw process
- Conversely, winter maintenance requirements may decrease in many areas due to a milder climate, whilst changes in springtime snow melt and the proportion of precipitation falling as rain or snow might result in less flooding

2.4 VULNERABILITY ASSESSMENT

In considering strategies to deal with the impacts of climate change on transport infrastructure, it is likely that a staged approach will be implemented. There are key road, rail, inland waterways, ports and airports across European Member States whose continued efficient function is vital to maintain European economic competitiveness, as well as social connectivity. These transnational assets are likely to take priority, followed by national, regional and local transport networks.

This Roadmap concentrates initially on the TEN-T network, based on the cost-benefit of maintaining the connectivity of key links; however, the technical principles of increasing resilience can be applied to all transport networks, and might be particularly relevant for urban networks. The TEN-T network represents the key transnational road, rail and inland waterway/ports assets, whose protection against the possible effects of climate change is imperative; this document focuses on the road sector, recognising its dominance within the overall transport network.

In considering resilience, the interdependency of other infrastructure elements, telecommunications and power is vital in maintaining a functioning transportation network, e.g. power and telecommunications are vital in ensuring that transport networks function efficiently, particularly public transport; equally, workers need to be able to access power plants and control centres to keep them operational.

2.5 AGEING INFRASTRUCTURE

The development of road infrastructure throughout Europe varies greatly. Some regions have largely complete networks, with some parts built more than 50 years ago. Extreme weather events and the long term effects of climate change, together with increasing traffic loads will put further strain on Europe's infrastructure. Maintaining this infrastructure and protecting it against climate and traffic conditions not envisaged at the design stage is of great importance, and cost effective solutions to extend the service life are required. Conversely, some regions are still developing their road infrastructure networks, and cost-effective solutions to design and construct new roads with in-built resilience are thus desirable.

2.6 TRANSPORT SERVICE LEVELS

In recognising that climate change will have various impacts in various regions of Europe, and that there is a critical network of transport modes that require protection, an obvious starting point would seem to be to determine the key infrastructure assets that might be at significant risk, and to agree service levels for various tiers of infrastructure.

For example, for the Tier 1, TEN-T networks that are key European transport corridors, it might be required that they operate at 99.99% availability, whereas local roads might be assigned a lower availability level based on the cost-benefit of keeping them operational. The point at which the service levels are set will have a significant bearing on the required adaptation measures.

As the dominant sector in terms of passenger and freight movements across Europe, the road sector is one which offers the greatest flexibility in terms of re-routing opportunities. In order to determine the Roadmap and the milestones, the first step is to determine what is envisaged by a climate resilient road; i.e. once a target is defined, the steps to achieve that target can be identified.

It will not be possible to make a road or transport system totally resilient to climatic events, and certainly not at an acceptable economic cost.

In working towards a 2025 timeline, the following specific targets are considered appropriate:

- The focus of this Roadmap is for the resilience of the core network (TEN-T), however the principles can be applied to all roads
- Service levels should be set, specifically with a target for a reduction in downtime of 50%; this will cover all aspects of downtime, and not just that related to weather events
- There is a target of at least three corridors that will be made resilient, with downtime reduced by 50% in accordance with the targets presented in FEHRL's fifth Strategic European Road Research Programme (SERRPV)
- Newly built roads and roads that are undergoing reconstruction will be designed to be resilient to the future predicted climate, and vulnerabilities should be accounted for and/or avoided. This requires 'Intelligent Road Design'
- There is a challenge in competence and skills shortage currently which should be addressed
- Maintenance and management costs and long term (life cycle) effects should be accounted for

In 2025, a climate resilient transport network will ensure that key routes are available at appropriate safety levels to the user in all weather and climate conditions. Effectively this means the network service might be limited for an acceptable period of time, but that routes that are key to the European economy and society would not be blocked. The selection of key road routes will be subject to a cost-benefit evaluation over the corridors/routes involved, which will consider not only the level of resilience achieved per spend, but factors such as the importance of the route for freight, connectivity between major conurbations and the availability (or lack) of alternative routes.

2.7 PREPARATION FOR THE USE OF E-MOBILITY, INTELLIGENT DRIVING SYSTEMS

Partly as a result of the predicted and observed increase in fossil fuel prices, and a requirement to reduce carbon emissions, there has been considerable research and development activity on the topics of e-mobility and intelligent driving systems. This will require central data servers to coordinate all information and activities. This is of relevance to the Resilient Road insofar as increased control and monitoring through, for example, sensor systems and intelligent driving systems, will allow road operators to implement traffic control measures in response to weather events, to provide routeing information, and will also enable vehicles to act as sensors and provide information on road and environmental conditions.

2.8 LAND USE PLANNING

In the future, the road network will need to interact strongly with its environment, for example by acting as a reservoir or flood barrier depending on location. As such, in developing a resilient transport network, links between transport and land use planning will be vital, and we therefore need to design research programmes with land-use and resilience to extreme weather in mind.

3. SCOPE AND APPROACH

Climate change will have an impact on all aspects of road transport. Currently, the transport network struggles with extreme weather events both in terms of operational disruption and damage to the highway infrastructure. Facing this situation, road authorities need to be supported with appropriate strategies to ensure the reliability, availability, maintainability and safety of road infrastructure.

This Roadmap aims to support road authorities by providing a research agenda that should enable a better understanding of climate risks and vulnerabilities, adaptation options and management strategies. The innovation themes and associated research requirements are designed to support the overarching milestones for 2015, 2020 and 2025-2030.

3.1 INNOVATION THEMES

This section presents a programme of research based on three innovation themes, and specific topics considered vital to facilitate transitions towards the Resilient Road, with a suggested approach and indicative milestones planning for each topic. These indicative milestones will not be representative for all European countries, as some Member States will be 'early adopters', whilst others will follow a timeline which suits their particular socio-economic situation.

There is a balance to be made in ensuring that the future road transport system is accessible, satisfies requirements for sustainable economic growth, and yet is resilient to climatic impacts. This requires a holistic approach covering the development and implementation of technologies and methodologies, and management and adaptation strategies as well as revised technical specifications. The research and innovation activities focus on a broad range of themes. The key themes are described below, with specific research and innovation topics presented in section 3.2.

Development and implementation of risk-based methodologies

1. Development of risk-based methodologies to assess the vulnerability of the road network to extreme weather events, longer term impacts of climate change and shifts in climatic zones.
2. From the results of the vulnerability assessment, production of maps showing potentially vulnerable elements of the TEN-T road network.
3. Estimation of economic costs of adaptation measures and development of risk-based procedures to consider the cost of disruption due to extreme weather versus the cost of adaptation.

Development and application of technologies

1. Design of resilient drainage systems, soil strengthening and rock stabilisation techniques, and early warning systems
2. Resilient asphalt and concrete pavements (mixture and pavement design, paving technologies) and methods of increasing skid resistance.
3. Resilient, long life and low maintenance measures for increasing the resilience of existing bridges, including foundations, pre-emptive protection systems for tunnel structures against flooding and solutions for the conservation of groundwater reserve during tunnel construction and operation.
4. Rapid and automated inspection and survey methods, as well as sustainable maintenance measures and techniques for pavement, sub-surface, structures and drainage.
5. Automated and remote sensors for measuring environmental conditions and change.
6. Interaction between vehicle/road/driver.

Development and introduction of management and adaptation strategies

1. Develop guidelines for the expected performance levels of infrastructure systems and guidelines to cope with restricted flow during extreme weather events.
2. Development and improvement of models to predict weather events and traffic congestion, and to assess the impact of real time management systems to provide the early warning of extreme events and instigate intelligent re-routing and modal shift.
3. Development and implementation of adaptation strategies and development of guidelines to assist implementation for new build and adaption of existing infrastructure.
4. Integration of the above with emergency services systems.
5. Sensor and communication systems to provide real time information for the road user.

3.2 RESEARCH AND INNOVATION TOPICS

Using these themes, the objectives and enablers relating to developing resilience in the performance and management of the TEN-T network have been established. The supporting research needs have then been identified, with a view to the application of practical measures for each theme.

Development and implementation of risk-based methodologies

Objective

To understand the vulnerability of the TEN-T road network to the effects of climate change, and understand the cost-benefit of adaptation options.

Enablers

- Climate projection models/climate impact models
- Vulnerability toolkits
- Cost-benefit techniques

Application

There are a number of vulnerability toolkits available, with the RIMAROCC method being used to assess sections of both the Dutch and German TEN-T networks. An additional tool is SWAMP, which, along with RIMAROCC, was developed as part of the 2009 ERA-NET Road call 'Road Owners Getting to Grips with Climate Change'. The FHWA has a five stage vulnerability assessment process, whilst other methods such as Bayesian Probability Networks are increasingly being used. The 2012 ERA-NET Road call 'Road Owners Adapting to Climate Change' will fund projects in climate modelling, vulnerability assessment and adaptation technologies that will be undertaken over the 2012 to 2015 period.

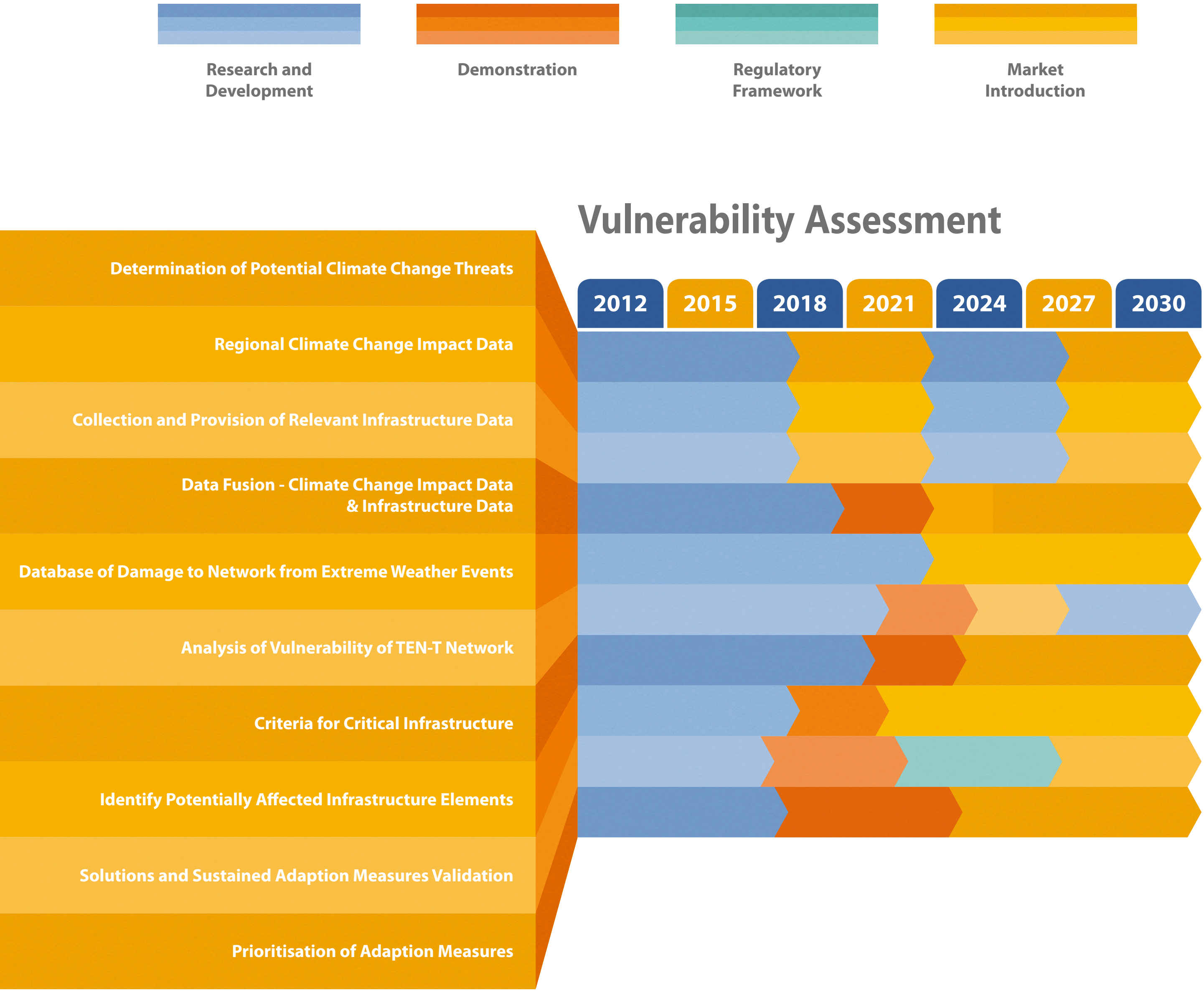
Regional climate simulations are now available for Europe and can be obtained from the ENSEMBLE website. Similarly, Gridded observational data are also available for Europe (e-obs) and can be used to make estimates of the current vulnerability to weather hazards[7].

Research needs

There is an on-going requirement for improved climate models, particularly in terms of downscaling from current predictions, and precipitation models; work is on-going on this topic in many meteorological centres worldwide, with communication and collaboration between climate scientists and highway professionals key to understanding risk and acting accordingly. Such co-operation will address areas of interest to road operators, such as the extent to which downscaling is necessary.

The harmonisation of existing climate projections is important as it will generate the resulting input data for vulnerability assessments suitable for national road authorities. This could enable a more precise definition of the impact of extreme weather events on infrastructure, e.g. the development of threshold values for rainfall, which could trigger a requirement for the adoption of adaptation measures or revised maintenance requirements. Further improvements and common acceptance on risk models are also required. There is a requirement for economic modelling on the potential future disruption caused by climate change, and the cost-benefit analysis of adaptation technologies, including common systems.

[7] Written communication from UK Met Office



Development and application of technologies

Objective

The objective is to develop and deploy cost-effective adaptation measures in order to increase the resilience of the TEN-T road network, whilst maintaining appropriate safety levels.

Enablers

- Existing adaptation measures/technologies
- Existing adaptation plans by, for example, sector, city, region, nation
- Cost-benefit analysis measures

Application

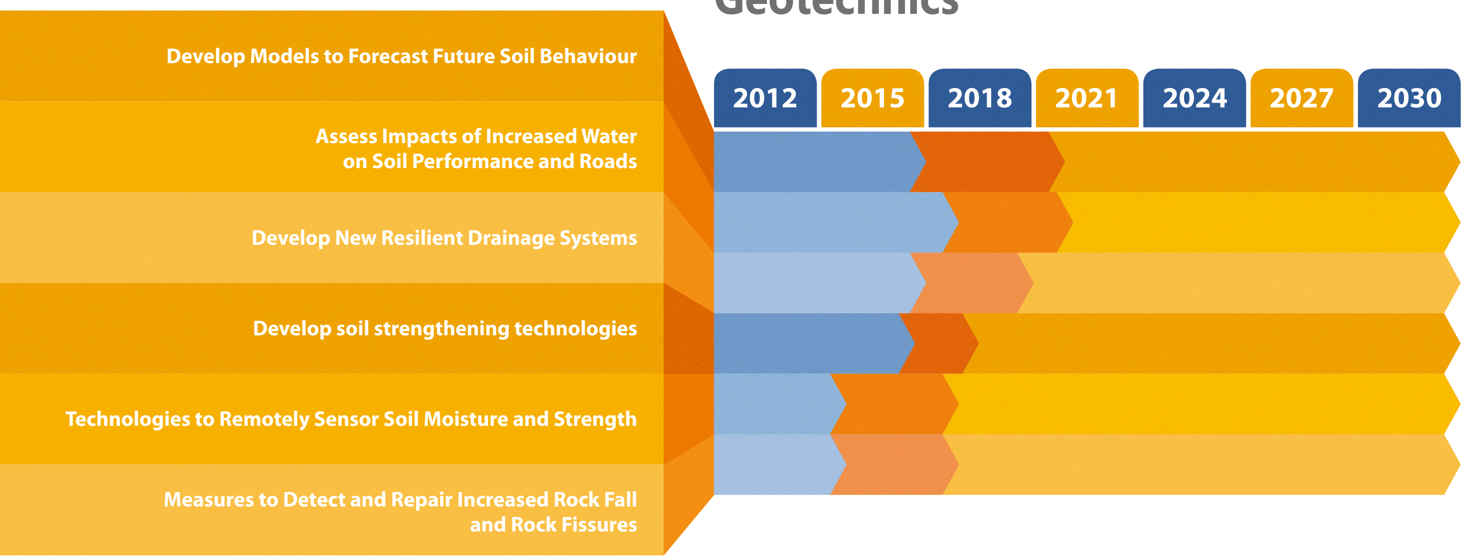
Different weather events will pose correspondingly different stresses to the various elements of the highway system; for example, extreme heat may increase the propensity for rutting on asphalt pavements, whereas an extreme rainfall event might affect the sub-base or embankment. The majority of the elements on the network are interlinked and interdependent to a greater or lesser extent, and as such consideration needs to be given to individual elements, e.g. running course, sub-base, sub-grade, embankments, drainage, structures, foundations and tunnels.

Research needs

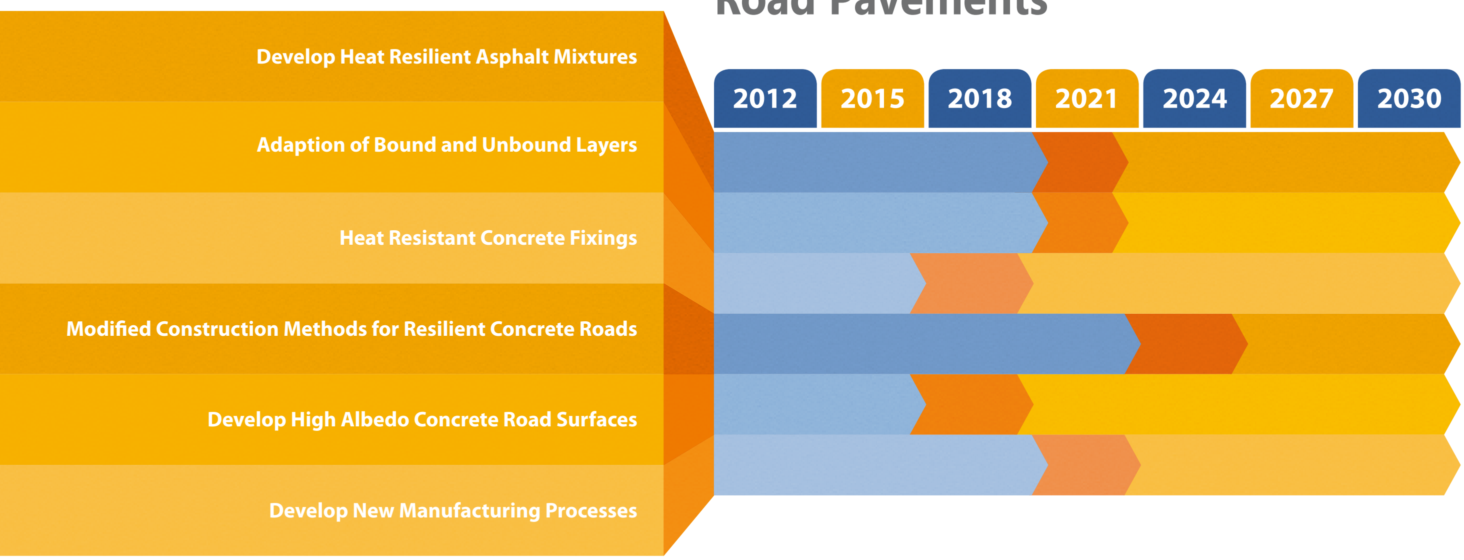
There is a need to improve both concrete and asphalt pavements to protect them from the effects of extreme weather, although better drainage at pavement surface and in the substructure is a most pressing need. Improvements in the drainage and resistance of the pavement sub-surface and embankments to fluctuations in extremes of water to prevent cracking through desiccation and strength loss or landslides through excess water are required. Additionally, bridges and structures, including foundations, require increased resilience to flooding and scour. For northern and possibly mountainous regions, there is a requirement to increase the resilience of the pavement to freeze-thaw actions.

There will be an interaction with the Adaptable Road Element in so far as technologies developed here will be implemented by the Adaptable Road, and research themes in the Adaptable Road such as self-healing and self-cleaning will increase the resilience of the road in general. The following research topics are divided into geotechnics, road pavements and bridges and structures, although the interaction between these components is acknowledged.

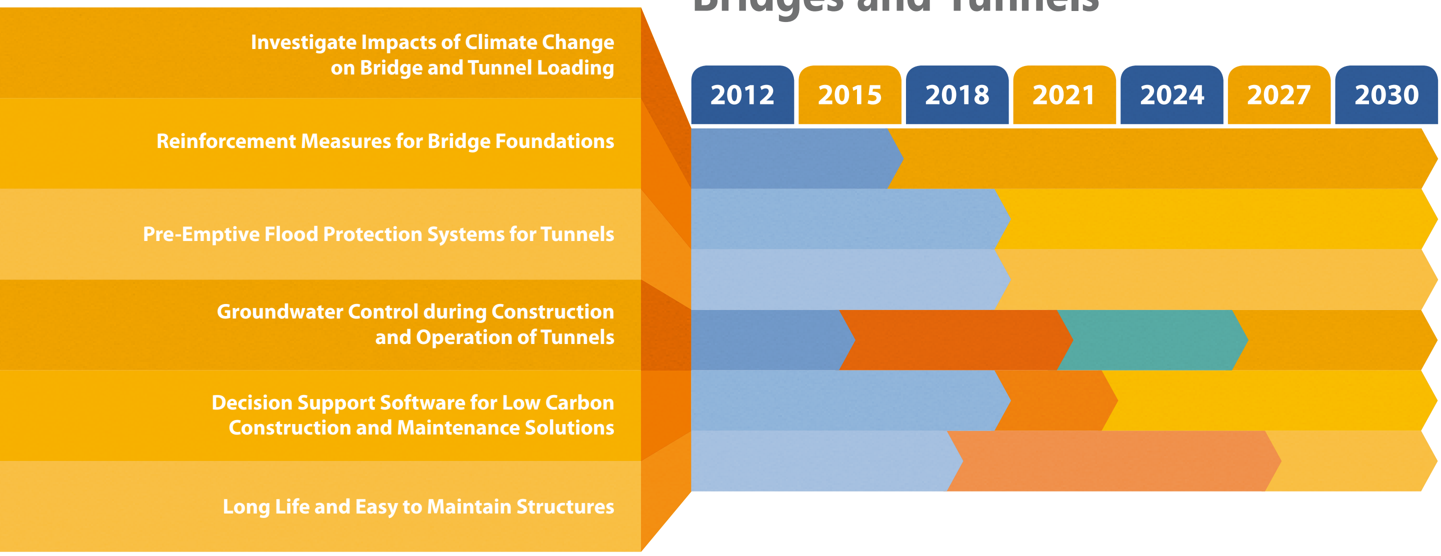
Geotechnics



Road Pavements



Bridges and Tunnels



Development and introduction of management and adaptation strategies

Objective

The objective is to improve the strategic planning and general management and operational response of the highway network to extreme weather events.

Enablers

- Existing asset management procedures
- Cooperative Intelligent Transport Systems (ITS) and communication systems
- Disaster management/emergency plans

Application

There are two separate but linked requirements regarding the strategic planning of the TEN-T network by the national road authorities. The first is to increase the resilience through understanding vulnerable sections and implementing adaptation mechanisms accordingly. The second requirement is the continued operation of the TEN-T network when challenging weather events are predicted or are occurring, in order to maintain as high a service level as possible.

Research needs

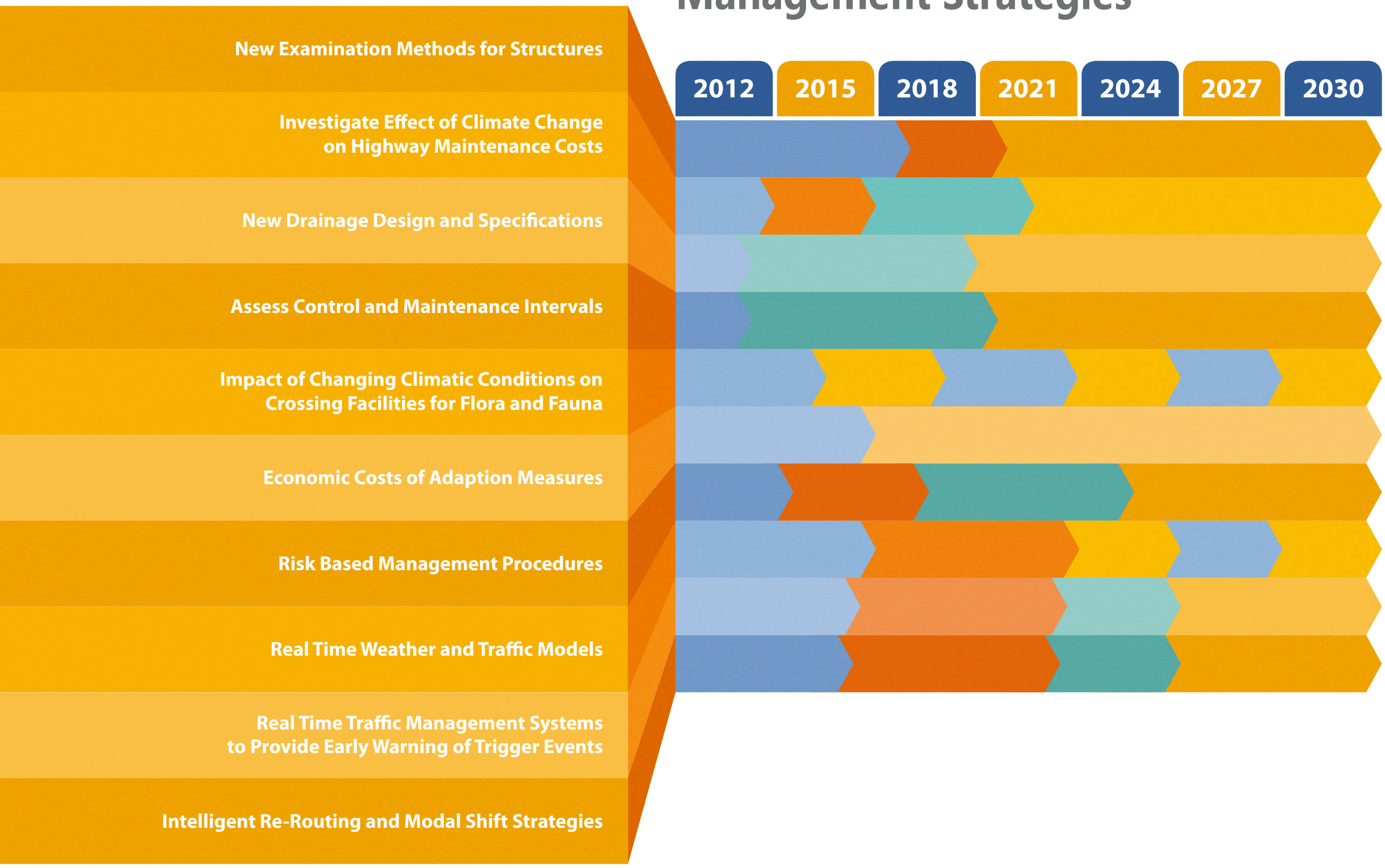
The production of guidelines on the required performance levels for infrastructure elements is required, in order to produce a baseline for climate change adaptation requirements.

Improved weather prediction models to be used in conjunction with real time weather and traffic information require development in order to provide early warning and trigger operational responses such as, for example, the restriction of access, changes to speed limits or re-routing. There is also a requirement for improved asset management, value management and maintenance strategies for the adaptation of infrastructure that will provide optimal cost effectiveness. An intermodal approach for adaptation measures should be considered.

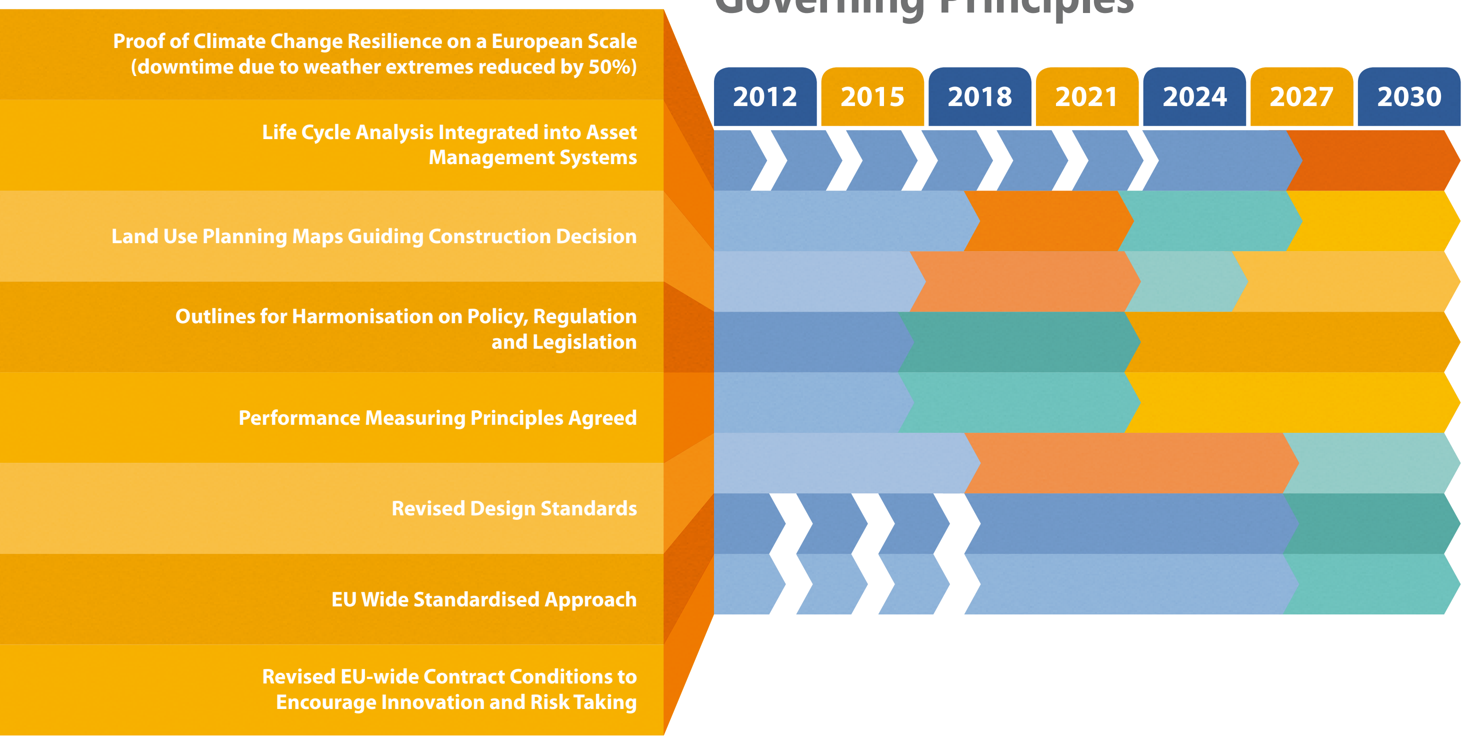
There should be interaction with the Automated Road Element in terms of data gathering from various sensor systems and networks and translating that into reliable and real-time information for road users. This will include the use of ITS for traffic control for environmental purposes in varying traffic/weather conditions, e.g. to reduce speeds in extreme weather conditions.

The research topics here come under Management Strategies, with focus on the day-to-day management of transport infrastructure, and Governing Principles, which concentrate on the national or European strategic management of transport infrastructure.

Management Strategies



Governing Principles



4. ROADMAP MILESTONES

The Roadmap will provide proven solutions that are ready to be implemented by the national, regional and local infrastructure authorities. The generic build up is from single technology trials from around 2013 towards full systems proving on a network scale around 2020. From 2020, the Roadmap will be concerned with supporting and facilitating the roll-out activities by the authorities. It is in this stage that climate change resilient transport will be implemented at a network level.

Milestones are proposed for 2015, 2020 and 2025 for short, medium and longer term implementation, respectively, and are outlined in Figure 2. It is recognised that research and development for different technologies would progress at different rates. This is indicated in Section 3. The Roadmap is intended to be an active document, and it is recognised that it covers a medium to long timescale; as such, it will be reviewed at regular intervals to recalibrate the targets and approach.

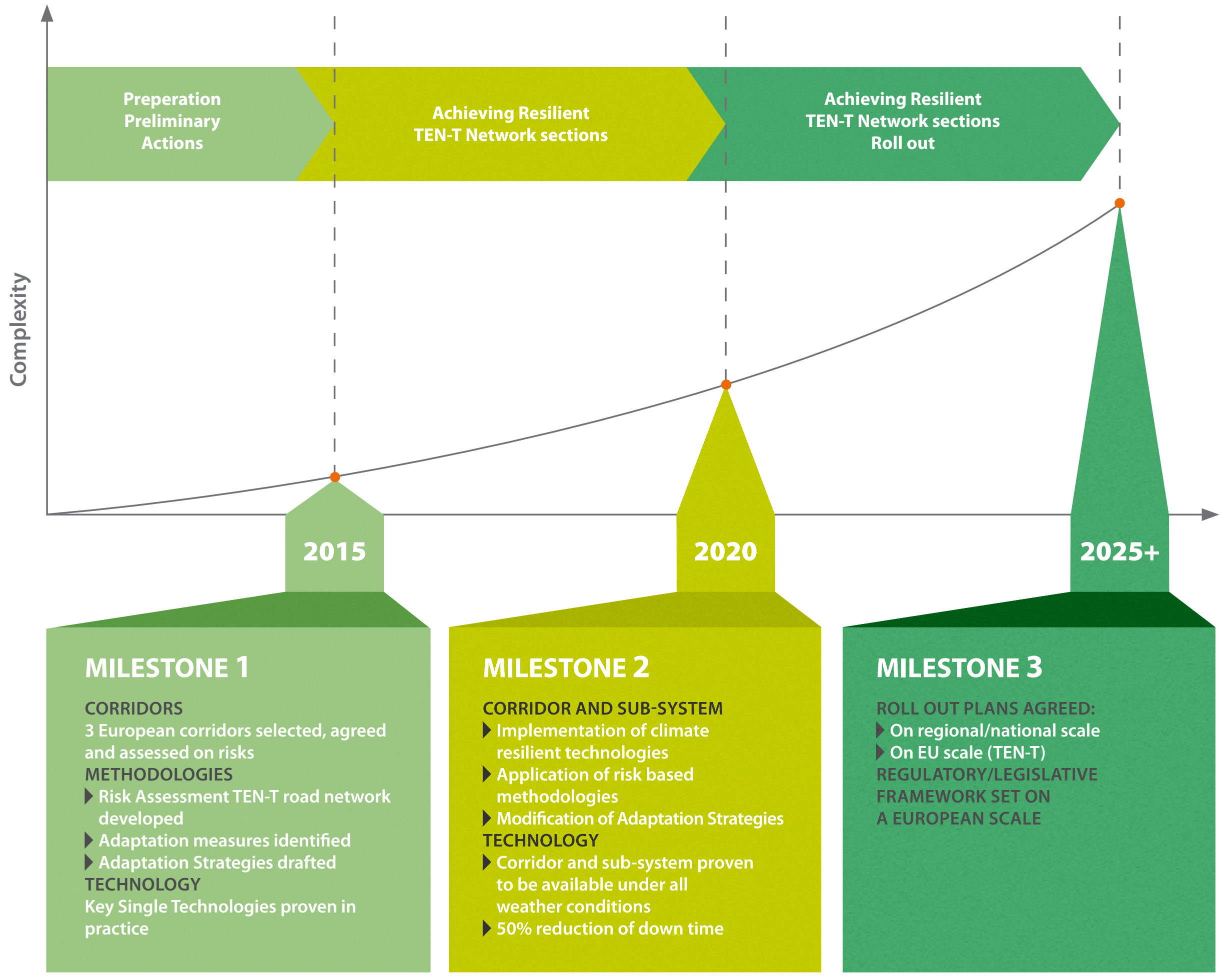


Figure 2: Outline Milestones for Climate Change Resilient Transport

4.1 MILESTONE 1: PREPARATION AND PRELIMINARY ACTIONS (2015)

The main topics of Milestone 1 are the selection of three TEN-T pilot corridors, the collection of background information and implementation of a unified database on transport-related climate change effects/scenarios and the application of single technologies on selected infrastructure elements.

Corridor selection

- Selection of three TEN-T pilot corridors.
- Preliminary assessment of weaknesses based on currently available methodologies (RIMAROCC, SWAMP and already available national tools).
- Development and updating of design standards for the predicted future effects of climate change and extreme weather events.
- Encouragement of road authorities to carry out pilot projects for eliminating identified weaknesses.

Methodologies

- Review, analysis and assessment of existing regional climate predictions regarding European transport needs.
- Fusion of regional climate predictions with the aim of gaining a unified knowledge database specific for European transport (TEN-T).
- Further development and improvement of existing risk-based methodologies for assessing the vulnerabilities of transport infrastructure.
- Identification of adaptation measures with regard to the possible vulnerabilities.
- Development of adaptation strategies and their implementation for existing infrastructure.

Technology proving

- Optimisation of identified adaptation measures and further development to enable deployment.
- Selection of infrastructure elements (e.g. structures, drainage elements as well as road pavement) for pilot applications.
- Single technology proving of selected adaptation measures/technology.
- Validation of technologies based on the results of pilot projects.

4.2 MILESTONE 2: ACHIEVING RESILIENT SECTIONS OF THE TEN-T NETWORK (2020)

By 2015, validated information on the adaptation technologies available can be provided. Unified information on regional climate change effects as well as the scenarios relevant for transport infrastructures will be available. Validated methodologies for the identification of vulnerabilities will have been proven. Key elements are:

Corridor and sub-system proving

- Implementation of climate resilient technologies will be undertaken on three pilot TEN-T corridors or sub-systems, such as city ring roads and transport interfaces
- Agreement on common specifications for identified routes
- Application of risk based methodologies for assessing the vulnerabilities of the three selected corridors/sub-systems (identification of hot spots; modification of adaptation strategies)

Technology proving

- On-going research on additional potential technical solutions
- Real time traffic management systems that monitor traffic and environmental conditions and provide an early warning of trigger events
- Improved weather and traffic prediction models
- Enabled technology on a systems level (i.e. integrated over materials and components, management strategies and policy and governing principles)
- Undertaking of cost-benefit analyses; evaluation on the sub-system level, including consideration of social implications of technologies applied on the pilot corridors
- Allied to the technical tasks, there should be the development of new national level management and governance processes

4.3 MILESTONE 3: ACHIEVING RESILIENT TEN-T NETWORK (2025)

It is expected that all technical solutions will have been tested and validated on sub-system level; cost-benefit analyses will have been carried out. The key task of milestone 3 is implementation of all technologies on system level (three TEN-T pilot corridors).

By 2025, all technologies for resilience should have been proven on a European scale, including sub-systems identified by 2020. At this stage, there will be a requirement to take best practice from the three routes, to learn and improve and to continue to deploy solutions more widely across the TEN-T network. From this point, technologies, operational strategies and governing principles will be fully integrated.

Underpinning this will be the development of governance and management systems with an overview at a European Union level; these will be based on risk-based asset and accessibility management. Allied to this will be transport and asset management strategies, at a European level with affiliates in Member States.

4.4 ROLL OUT: 2025 AND BEYOND

By 2025, the methodologies and technologies will have been demonstrated on live highways and will be ready to implement. As various National Road Authorities will have been involved in the programme, the process of dissemination and implementation will already have begun in earnest. Further implementation by Member States will continue after this time. The research will not stop in 2025 as systems and technologies will be improved and refined, and have additional features added.

5. REFERENCE TO NATIONAL PROGRAMMES

In delivering the Forever Open Road Programme, co-operation will be sought with a number of 'sister' National Programmes with shared aims and goals. It is envisaged that there will be a two-way exchange of ideas and information on work packages, as well as the sharing of research expertise, test facilities and demonstrators. Furthermore, there will be a need to validate results and test interoperability, which will require co-operation across equipment and product manufacturers, and infrastructure owners. The sister programmes that are already under development and with which co-operation will be encouraged are described below.

5.1 ROUTE 5ÈME GÉNÉRATION – R5G (THE 5TH GENERATION OF ROADS) - FRANCE

In synergy with the Forever Open Road Programme, FEHRL member IFSTTAR has launched the "5th Generation of Roads" programme, which aims to design full scale demonstrators integrating the numerous innovations that are already available within research centres, and demonstrating the synergies among them.

Methodology

The programme is organised into a 2D matrix. The first dimension deals with the type of network: urban, peri-urban, interurban and local networks. In the second dimension of the matrix, the research themes are organised into the following interdependent elements, like the Forever Open Road Programme:

- The **adaptable road** - dealing with the low carbon design, construction and maintenance of roads.
- The **resilient road** - relating to the resilience of road networks regarding climate change and their energetic efficiency.
- The **automated road** – dealing with the automation of traffic and operations using ICT.
- The **acceptable road** – dealing with the socio-economic aspects of the programme, in order to facilitate its implementation. In particular, this fourth element aims at developing a system approach along with the associated tools to ensure that the different societal objectives of the programme are likely to be reached.

Sub-system proving – design and construction of full scale research demonstrators

Given the complexity of the complete implementation, it is not relevant to directly design and construct a full R5G demonstrator. It is thus proposed to start with sub-R5G demonstrators. The first phase (2010-2014) is dedicated to the testing and labelling of single innovations, which are ready to be implemented in research demonstrators. The second phase (2014-2018) will be devoted to the integration of several innovations in a few selected research demonstrators which, in the end, will ultimately make it possible to design a full R5G demonstrator (2020) through the cross-fertilisation of the different research demonstrators.

[8] http://www.foreveropenroad.eu/?m=19

Four topic areas are considered for the programme:

- Co-modality urban space
- High Speed Automation of Roads
- Road and Energy
- Efficient and Self-Explaining Local Road Networks

5.2 STRASSE IM 21. JAHRHUNDERT (ROAD IN THE 21ST CENTURY, R21C) – GERMANY

Federal Ministry of Transport, Building and Urban Development

The objective of the German research programme "Strasse im 21. Jahrhundert" (Road in the 21st Century) is to further develop the road in a functional way. Regarding the main use of the roads (interconnectivity), this process shall lead to safer, more economical, efficient, reliable and intelligent roads. In addition, it should provide innovative uses. Hence, the existing and future demands on the "road" system and the new global challenges are fully taken into account as part of a holistic approach.

Based on future requirements and new challenges, seven thematic priorities were established. For each theme, road-related innovations will be identified, further developed and transferred into practice based on a holistic assessment. The thematic priorities are:

A. The safe and reliable road

A central goal is to enable the secure, efficient, predictable and reliable transportation of people and goods over short and long distances. In order to reach this, the management of road sites, disruption, security and maintenance is improved, especially for the most important network elements (nodes, bridges and tunnels). Information from vehicles in the road-side information and management systems are integrated and communication to interface with safety systems is supported. Hence, efficient traffic management is made possible by meeting the information needs of each individual road user.

B. The intelligent road

The aim is to enable traffic management and road maintenance to take better operational and strategic decisions. In order to achieve this, the continuous monitoring of the state of the road and structures, of the traffic and road safety as well as the required sensor technology are further developed and integrated. "Intelligent" materials and designs measure and analyse information, e.g. pressures and influences, and react independently. All sub-systems, i.e. materials, construction, information and communication, are to be integrated into an overall system.

C. The energy-saving road

The energy consumption for planning, construction and operation will be minimised and provided where possible by renewable energy. For this purpose, solar, geothermal and wind energies in the vicinity of roads are proposed and new building materials and technologies (e.g. LED) and construction methods with the lowest possible energy consumption are to be used. The CO_2 emissions from the production and disposal of building materials and CO_2 emissions in the construction of roads will be lowered to a minimum.

D. The low emission road

The compatibility of road traffic with the requirements of emission protection is an essential element for the acceptance of motorised road traffic. With new and improved versions of standard construction methods, the traffic noise will be reduced significantly at the source. Techniques to minimise traffic-related emissions by the degradation and retention of pollutants are integrated. A classification comprehending all targets for road surface and construction will allow the selection of designs adequate to the situation.

E. The road as part of the environment

The road is part of our living space and an essential basis of everyday life. At the same time, negative impacts of road traffic are to be minimised, especially in urban areas. Vulnerable road users such as pedestrians and cyclists, as well as people with limited mobility need to be protected to allow their active participation in the barrier-free traffic. The effectiveness of measures to improve the amenity value and to reduce fragmentation effects should be analysed. By this, the effect of roads on the quality of human life as well as on nature and environment are already considered in the planning of transport routes.

F. The sustainable road

The consideration of economic, ecological and social aspects in the life cycle of transport infrastructure is a prerequisite to ensure the mobility of our society in the long term. Sustainability and (energy) efficiency are already important objectives of the German federal government. The Road in the 21st Century Programme aims to establish a balance between economic, ecological and social aspects. The elements of road infrastructure will be considered as a whole over its lifetime, taking into account sustainability issues in the planning, choice of building materials and construction methods, maintenance and dismantling.

G. The road as a future innovator

The wave of innovation in vehicles of the 21st Century has to be complemented by an adequate infrastructure. In addition to its function as a transport route, the Road in the 21st Century has been established as an innovator and part of a positive national and European innovation climate. In order to develop building materials and construction methods that are innovative and less expensive over the entire life cycle and to transfer them as quickly as possible into practice, a test section shall be constructed. In addition, simulation techniques are also integrated into the assessment methods.

5.3 COASTAL HIGHWAY ROUTE E39 – NORWAY

Coastal highway E39

Statens vegvesen

Norway's coastal highway E39 is part of the European trunk road system. The route runs along the western coast of Norway, from Kristiansand in the south to Trondheim in central Norway, a distance of almost 1,100 km. The newly initiated project Coastal Highway Route E39 has been commissioned by the Norwegian Ministry of Transport and Communications to clarify the technological challenges and possibilities and to explore the benefits for industry and for society at large of developing the route into a more efficient corridor with no ferry connections. This project may reduce the travel time along the coast from Kristiansand to Trondheim by 7-9 hours, to a total of about 12-13 hours.

There are eight ferry connections along the route; most of them are wide and deep fjord crossings that will require massive investments and longer spanning structures than previously installed in Norway. The current travel time of 21-22 hours between Kristiansand and Trondheim is also influenced by the overall road standard of the route.

One of the objectives of the study is to substantiate the costs of construction, operations and maintenance, and the benefits for the society at large in a life cycle perspective of e.g. 50 years. Furthermore, this project will explore the technology required for the remaining fjord crossings. In addition to these two components, the project will consider how the road and bridge infrastructure can be utilised to generate power from solar energy, currents, waves and wind.

The feasibility study contains four components:

- **Society:** likely impacts on national and regional economies, trade and industry, and employment and settlement patterns
- **Fjord crossings:** technological challenges and alternative concepts for crossing the fjords
- **Energy:** how bridge structures can be utilised for power generation from renewable sources such as solar energy, winds, waves and tidal currents
- **Implementation strategies and types of contracts:** the most appropriate and best approaches for implementing and financing a project of this magnitude and complexity.

5.4 EXPLORATORY ADVANCED RESEARCH PROGRAM (EAR) – USA

EXPLORATORY ADVANCED RESEARCH

U.S. Department of Transportation Federal Highway Administration

Exploratory advanced research focuses on long-term, high-risk research with a high payoff potential. It matches opportunities from discoveries in science and technology with the needs of specific industries. In 2005, legislation established the EAR Program at the Federal Highway Administration (FHWA) in the United States Department of Transportation with up to $14 million in annual funding for breakthrough research with the potential for dramatic long-term improvements to transportation systems-improvements in planning, building, renewing, and operating safe, congestion-free, and environmentally sound transportation facilities.

The FHWA EAR Program has engaged international experts by sponsoring scanning tours, convening forums, inviting expert reviewers, and offering post-doctoral research fellowships. FHWA expects to continue these ad hoc collaborations and to formalise longer term relationships as part of Forever Open Road that could lead to joint research funding or paired projects.

EAR Program focus areas

The EAR Program funds research across a range of issues that are critical to the transportation industry:

- Connected highway and vehicle system concepts
- Breakthrough concepts in material science
- Human behaviour and travel choices
- New technology and advanced policies for energy and resource conservation
- Technology for assessing performance

In addition to the above, the programme also conducts cross-cutting research in the fields of nano-stage research and information sciences.

EAR Program results

The EAR Program has now completed six solicitations and is in the process of making awards on a seventh. As of September 2012, the programme completed awards for 50 research projects, 37 of which are on-going, totalling about $42 million in government funds and about $17 million in matching resources. In addition to sponsoring EAR projects that advance the development of highway infrastructure and operations, the EAR Program is committed to promoting cross-fertilisation with other technical fields, furthering promising lines of research, and deepening vital research capacity.

ANNEX 1

The table below provides details of the people and organisations that assisted in the development of this Roadmap

Workgroup	Organisation	Country	Role
Bob Collis	TRL	UK	Steering Group FOREX[9] Chairman
Martin Lamb	TRL	UK	Steering Group FOREX[9] Secretary /Co-workgroup Leader
Markus Auerbach	BASt	Germany	Workgroup Leader
Ursula Blume	BASt	Germany	Core group member
Sarah Reeves	TRL	UK	Core group member
Lucy Phillips	TRL	UK	Core group member
Christian Stefan	AIT	Austria	Core group member
Karoline Alten	AIT	Austria	Core group member
Sten de Wit	TNO	Netherlands	Supporting Organisation
Jos Wessels	TNO	Netherlands	Supporting Organisation
Steven Mookhoek	TNO	Netherlands	Supporting Organisation
Gordana Petkovic	NRPA	Norway	Supporting Organisation
Caroline Evans	ARRB	Australia	Supporting Organisation
John Harrison	UK Met Office	UK	Supporting Organisation
Carlo Buontempo	UK Met Office	UK	Supporting Organisation
Fredrick Hellman	VTI	Sweden	Supporting Organisation
Jeffrey Perlman	NJTPA	USA	Supporting Organisation

[9] The Forever Open Road Experts Group (FOREX) was formed in January 2011 to take forward the technical development of the Forever Open Road following completion of the Forever Open Road R&D plan undertaken by the Scoping Group. Activities have included contributing to the development of FEHRL's SERRP V document and the development of the Roadmaps for the three elements.

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