STRIA - TRANSPORT INFRASTRUCTURE

2019 update based on original 2016 version

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ACRONYMS

ATM	Air traffic management
CEDR	Conference of European Directors of Roads
CEF	Connecting Europe Facility
C-ITS	Cooperative intelligent transport systems
COST	Cooperation in Science and Technology
CSA	Coordination and support action
EC	European Commission
EeB cPPP	Energy-efficient-building contractual public-private partnership
EIB	European Investment Bank
EIM	European Rail Infrastructure Managers
ERTMS	European Rail Traffic Management System
ETP	European Technology Platforms
ETS	Emissions Trading System
EU	European Union
FP	Framework programme
FTI	Fast track to innovation
GDP	Gross domestic product
GHG	Greenhouse gas
ICT	Information and communication technologies
IEA	International Energy Agency
ITS	Intelligent transport systems
JU	Joint undertaking
MS	Member States
NTIA	National Transport Infrastructure Authorities
PPP	Public-private partnerships
R&I	Research and innovation
SDGs	Sustainable development goals
SERA	Single European railway area
SES	Single European Sky
SHM	Structural health monitoring
SME	Small and medium-sized enterprises
STRIA	Strategic transport research and innovation agenda
TEN-T	Trans-European transport network
TRIMIS	Transport research and innovation monitoring and information system
TRL	Technology readiness level

1. INTRODUCTION

The 2011 transport white paper, *Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system* (European Commission, 2011), states:

Infrastructure shapes mobility. No major change in transport will be possible without the support of an adequate network and more intelligence in using it. Overall, transport infrastructure investments have a positive impact on economic growth, create wealth and jobs, and enhance trade, geographical accessibility and the mobility of people. It has to be planned in a way that maximises positive impact on economic growth and minimises the negative impact on the environment.

In 2017 the European Commission took a further step in the modernisation of European mobility and transport: it published the first mobility package to help the sector to stay competitive in a socially fair transition towards clean energy and digitalisation. As part of the package, a staff working document was drafted, which focused on the creation of a strategic transport research and innovation agenda (STRIA). That document included a forward-looking agenda for research and innovation (R&I) in transport, which addressed seven priority areas in the form of roadmaps.

Among these roadmaps, the first STRIA roadmap on transport infrastructure[1] was published in 2017. It assessed what was needed to ensure that infrastructure meets the environmental policy objectives. To assist in this assessment, the STRIA sought to identify the areas where the next generation of R&I was likely to be of greatest benefit. This first roadmap identified the areas of: governance; pricing, taxation and finance; intermodality, interoperability and integration of transport systems; life-cycle optimisation; and the operation and digitalisation of infrastructure.

To include new developments in transport and to address several gaps in previous roadmaps, the Commission had planned to update several STRIA roadmaps in 2019, of which the roadmap for transport infrastructure was one. Although the development of the first STRIA roadmap on transport infrastructure in 2016-2017 was mainly focused on the goal of decarbonisation, this updated version adopts a wider approach. Decarbonisation is still an objective, but other aspects are also being considered, such as: the competitiveness of European industry; territorial cohesion; multimodality; services for visitors and the public; safety and security; etc.

[1] In this context, infrastructure comprises the basic physical facilities and installations necessary for the operation of road, rail, civil aviation, inland waterways and shipping. Infrastructure also comprises the additional infrastructure necessary for: (i) the propulsion and refueling of transport vehicles; (ii) the coordination, monitoring and management of transport; (iii) ensuring secure and safe operation; and (iv) transfer of passengers and freight.

Transport infrastructure as a fundamental enabler of progress

Transport infrastructures are key elements in many of the United Nations sustainable development goals (SDGs) (United Nations). For example, SDG 1 speaks of how transport infrastructures can help in the fight against poverty; while SDGs 3 and 4 speak of how they can provide access to health and education services. SDG 8 refers to their role in supporting economic growth, while SDG 11 talks of their role in the development of cities. On top of this, infrastructure is one of the three subjects of SDG 9 'Industries, innovation and infrastructure', where the United Nations states the following:

Investments in infrastructure – transport, irrigation, energy and information and communication technology – are crucial to achieving sustainable development and empowering communities in many countries. It has long been recognized that growth in productivity and incomes, and improvements in health and education outcomes require investment in infrastructure.

Infrastructure has been a key area of the recent EU R&I programmes. In the last Horizon 2020 work programme (valid for 2018-2020), transport infrastructure was mainly included under the 'Societal challenges' heading, and especially under the 'Smart, green and integrated transport' challenge. There were also some references to infrastructure in other areas (e.g. the Small and Medium Sized Enterprises instrument, Fast Track to Innovation, etc.).

The next R&I framework programme (FP) for 2021-2027, Horizon Europe, had not yet been published at the time this report was being written. However, there has already been an announcement that Horizon Europe will fund €100 billion in research investment (European Commission) , with €15 billion directed towards the 'Climate, energy and mobility' cluster. This will make Horizon Europe the most ambitious funding programme ever.

Document structure

This STRIA roadmap on transport infrastructure is organised as follows:

(i) chapter 1 includes an introduction and describes the **background** of the STRIA initiative;
(ii) chapter 2 introduces the vision and objectives of the STRIA transport infrastructures roadmap;
(iii) chapter 3 presents the 'state of the art' of different R&I initiatives at the EU level;
(iv) chapter 4 introduces the main future challenges for transport infrastructure. These challenges are the basis for the R&I priorities;
(v) chapter 5 presents the priorities for R&I in transport infrastructures, showing different thematic areas and actions;
(vi) chapter 6 sets out a strategic implementation plan;
(vii) chapter 7 summarises the key parts of the roadmap in the conclusions;
(viii) annex 1 includes a detailed state of the art of R&I in transport infrastructure;
(ix) annex 2 presents the interdependencies between this roadmap and other roadmaps.

This roadmap is linked to other STRIA roadmaps[2], as transport infrastructure is a key part of a more integrated and effective transport system. There are many interdependencies among the seven roadmaps, which should be considered as a group (see Annex 2).

2. VISION AND OBJECTIVES

2.1. VISION: TRANSPORT INFRASTRUCTURE OF THE FUTURE.

A common Europe-wide approach to transport infrastructure aims to deliver innovative design, construction, maintenance and upgrading concepts to improve the performance of the existing transport environment in a user-centric way. Mobility as a service will take intermodality to the next level, connecting many modes of transport into seamless door-to-door services for people and goods.

Infrastructure networks will be designed, built, operated and maintained in a sustainable way. This will reduce resource and material consumption; ensure minimal environmental impact; increase resilience to climate change; and increase safety and security.

Smart governance will be designed and implemented using a consistent and multimodal framework. This will be achieved using lean-procurement and risk-assessment methodologies.

The integration between transport infrastructure and digital technologies will provide personalised seamless journeys across different transport modes. This integration will consider safety as from the design phase, while simultaneously automating and accelerating the decision process at every level from maintenance to traffic management.

Innovative infrastructure will be fully digitalised and networked; this will include all airports and bus and train stations, as well as all command-and-control systems. Real-time monitoring of the condition of transport infrastructure by a wide array of sensors will improve the decision processes for predictive maintenance. Robust and modular infrastructure assets will be efficiently maintained and repaired using robotic automated systems. This will ensure that the maintenance and repair operations are punctual and safe, increasing capacity and decreasing the cost of operations.

By 2050, rail transport in Europe will be a fundamental element supporting intermodal ‘mobility as a service’ within cities and beyond, for both passengers and goods (European Rail Research Advisory Council, 2012).

The creation of a single European rail area will facilitate operational interoperability and intelligent traffic management.

[2] STRIA integrates seven thematic transport research areas: cooperative, connected and automated transport; transport electrification; vehicle design and manufacturing; low-emission alternative energy for transport; network and traffic management systems; smart mobility and services; and infrastructure.

The European waterborne transport sector will meet the demand and sustainability challenges by: (i) providing seamless connections between transport modes; and (ii) being fully integrated with 'green' and 'smart' multimodal ports.

By 2050, port infrastructure and operations will be increasingly integrated with waterborne and hinterland logistics by adapting near-shore extensions and offshore ports (Waterbone Technology Platform). While adapting to climate change, ports will create flexible and resilient solutions for: (i) future ships and vessel types; and (ii) new port activities.

Major changes in aviation ground infrastructure (airports, urban helipads and facilities to support new air vehicles and concepts) will offer passengers a vastly improved seamless travel experience.

Air-transport interface nodes will deliver the best possible customer-centric infrastructure layouts, which will integrate fluently with other transport modes.

Road transport infrastructure, together with new vehicle designs, will enable people and goods to reach their destinations in a safe, affordable, reliable and comfortable way. Interchange infrastructures will ensure smart and seamless intermodality, minimising the length of the door-to-door journey.

The network for future freight operations and their associated logistics hubs will evolve to facilitate smart, competitive and unhindered flows of traffic and goods.

The development and optimisation of a future multimodal transport system supported by appropriate evaluation capabilities will enable the best decisions to be taken at each stage of the process, from research planning to choices on policy and infrastructure.

Digital traffic management, at European and local level, will provide highly efficient road-network services that are safe and environmentally friendly. Digital traffic management will simultaneously guarantee competitiveness and accessibility, while promoting development.

2.2. OBJECTIVES

Transport systems are a fundamental part of our modern social and economic life. For the EU, transport systems allow the free movement of goods and services; enable the generation of economic wealth across all Member States; and facilitate the import and export of goods and services to and from different regions.

EU transport infrastructure faces several key challenges, the most significant of which are: governance; pricing, taxation and finance; the syncromodality, intermodality, interoperability and integration of transport systems; life-cycle optimisation; construction; operation; safety; and security.

The STRIA roadmap for transport infrastructure aims to: (i) map out plans for R&I in these key areas; (ii) test new methodologies; and (iii) pave the way for future transport infrastructure policies.

The objective of this 2019 revised version of the STRIA transport infrastructure roadmap is to update and outline future transport R&I priorities. While the 2017 roadmap focused on

decarbonising the European transport sector, this revised roadmap also seeks to include other priorities, such as ensuring competitiveness, safety, security, cohesion, intermodality, etc.

By concentrating on the infrastructure aspects of transport, this roadmap assesses these new priorities in order to meet wider policy objectives. This roadmap also seeks to identify the areas where the next generation of R&I is likely to be of greatest benefit. These challenges are laid out further in this roadmap.

This STRIA roadmap supports the vision of a clean, connected and competitive European transport system. In coordination with Member States and transport stakeholders, this roadmap aims to set out common priorities to support and speed-up the research, innovation and deployment process. It is hoped that this will lead to radical technology changes in transport. Like its predecessor version, this roadmap provides an overview of the mega-trends and challenges at EU and global level.

3. STATE OF THE ART

This chapter gives a recap of the European policy context of the last 10 years in: (i) investments; and (ii) R&I through the successive FPs. It shows how these two factors have been used to support and develop a well-functioning single European transport area.

There is robust evidence on the relationship between: (i) the quantity and quality of transport infrastructure and the level of investment in efficient transport systems[3]; and (ii) the level of economic development.

Transport infrastructure has a long life-cycle, and this has implications for the availability of financing, particularly considering the limited availability of public resources. Since the global economic crisis in 2008, the EU has invested less in transport infrastructure. According to a recent European Commission study on current trends and issues in the transport sector (European Commission, 2018) (European Commission 2018), this shortage of investment has held back modernisation of the EU's transport system. The European Investment Bank (EIB) estimates that the infrastructure investment gap in the mobility sector is €50 billion annually, i.e. 0.38 % of the EU's gross domestic product (GDP) (European Investment Bank, 2018).

At a European level, many stakeholders from the transport or construction sector have been working together to draw up a list of necessary R&I activities in the European technology platforms. They have invested for a long time in different European projects, supplementing the activities carried out at Member-State level.

3.1. POLICY CONTEXT

In its 2011 white paper (European Commission, 2011), the European Commission adopted a roadmap of 40 initiatives for the next decade to build a competitive transport system that will increase mobility; remove major barriers in key areas; and support growth and employment. Of these 40 initiatives, 6 are explicitly dedicated to 'modern infrastructure and smart funding'.

[3] Investment in efficient transport systems benefits direct users by saving them time, but it also provides wider economic and social benefits in terms of increased productivity, employment, and investment effects elsewhere in the economy.

Nevertheless, in the 2016 assessment of the implementation of the white paper (European Commission, 2016), it was recognised that there had been unsatisfactory progress towards the goals set in 2011. The assessment said the following.

Despite a relative good pace on the side of the Commission in proposing new measures, it has become evident that the follow-up adoption of the proposals by the legislators as well as the implementation have been lagging behind. Moreover, it has turned out that not all initiatives could take the form initially planned and alternative approaches to tackle various problems are sometimes needed. Despite the continuation of the main trends, it should also be acknowledged that the current situation has evolved since 2011. The rapid technological developments (notably due to automation and digitalisation) have been reshaping mobility concepts and opening new potentials.

Transport activity across Europe remains high, and is set to continue growing. Estimates suggest that passenger transport could increase by 42% by 2050, and freight transport by 60% by 2050 (European Commission, 2019). This increase will put pressure on the transport network and the environment. A lack of capacity is already being felt in some sectors, generating heavy costs for travellers and businesses alike.

Solutions to this structural challenge (a growing need for mobility set against a lack of infrastructure investment) must not divert the EU from meeting its targets for reductions in greenhouse gas (GHG) emissions. Overcoming this challenge requires creative and innovative solutions.

But capacity limitation and climate change are not the only factors affecting transport. Since the last major revision of EU transport policy in the 2011 white paper, new trends have emerged in technology, society and economics. These trends include: the collaborative economy; digitalisation; big data; increasingly complex business structures and supply chains; the circular economy; and threats such as cybercriminality or terrorism.

In September 2012, the European Commission issued to the Council and the European Parliament a strategy document entitled *Research and innovation for Europe's future mobility - Developing a European transport-technology strategy* (European Commission, 2012). The document proposed creating an R&I area under the heading 'Infrastructure and smart systems', and highlighted how such an R&I area would address three fields related to the white paper goals:

- smart, green, low-maintenance and climate-resilient infrastructure;
- Europe-wide alternative fuel distribution infrastructure;
- efficient, modal traffic-management systems (incl. capacity and demand management).

In July 2016, the Commission issued another document, *A European Strategy for Low-Emission Mobility* (European Commission, 2016), which emphasised multimodal core-network corridors and infrastructure for alternative fuels. This document also stressed that R&I increases competitiveness.

In May 2017, the Commission took action towards a fundamental modernisation of European mobility and transport by proposing 'Europe on the move' (European Commission, 2017), a wide-ranging set of initiatives. As part of this proposal, the Commission released another document, *Towards clean, competitive and connected mobility: the contribution of Transport -*

Research and Innovation to the Mobility package (European Commission, 2017). This document discussed seven priority areas that cut across the different modes of transport. Altogether, the Commission said that these seven areas formed a strategic transport research and innovation agenda. One of the items on this agenda was infrastructure.

In November 2017, the Commission issued an action plan with several actions and investment solutions for the trans-European deployment of alternative fuels infrastructure as part of a global package of new policies (European Commission, 2017).

In May 2018, the Commission completed its 'Europe on the Move' (European Commission, 2018) agenda for safe, clean and connected mobility with the communication *On the road to automated mobility: An EU strategy for mobility of the future* (European Commission, 2018). The part of this communication under the heading 'Making the EU stronger on technologies and infrastructure for automated mobility' argues that significant investments would be needed to develop the relevant technologies, create the necessary infrastructure support, and ensure social acceptance for automated mobility.

The trans-European transport network (TEN-T) is a project to help shape networks of transport infrastructure so they serve European needs. The EU adopted a regulation (European Parliament and Council, 2013) providing guidelines for transport investments. The regulation also created a legally binding obligation for EU countries to develop so-called core and comprehensive TEN-T networks. In addition, the regulation identified projects of common interest. The Connecting Europe Facility (CEF) Regulation, adopted in 2013, allocated a seven-year budget (2014-2020) of €30.4 billion, of which €24 billion was earmarked for the transport sector.

As part of the next long-term EU budget for 2021-2027, the Commission proposed in June 2018 to renew the CEF with €30.6 billion to support investment in European transport infrastructure networks (European Union).

The CEF will support smart, sustainable, inclusive, safe and secure mobility, in line with the 'Europe on the Move' proposals and the EU's transport infrastructure policy. It will support the decarbonisation of transport by prioritising environmentally friendly modes of transport and the development of charging points for vehicles that use alternative fuels. The Commission is also proposing a stronger emphasis on the modernisation of the transport network, in particular to make transport infrastructure safer and more secure. For the first time ever, the CEF will also support civilian-military dual-use transport infrastructure, to which it will give €6.5 billion in funding. The objective of this funding is to adapt Europe's transport network to military requirements and to improve military mobility in the EU. This will make an important contribution to a fully-fledged defence union by 2025, a political priority of the Commission.

In March 2019, the Directorate-General for Mobility and Transport published *Transport in the European Union – Current Trends and Issues* (European Commission, 2018), part of which was devoted to deficiencies in transport infrastructure. The publication said that: (i) since the global economic crisis, the EU had been suffering from low levels of investment in transport infrastructure; and (ii) the TEN-T development required investment in new infrastructure, infrastructure refurbishment and infrastructure modernisation.

The financing of transport infrastructure by efficient pricing and the internalisation of the external costs remains a key topic of European transport policy. The 2011 white paper stressed the wider application of the 'polluter-pays' and 'user-pays' principles. These principles mean that transport users should pay through charges, taxes, fares or other market-based

instruments (e.g. an emissions trading system) for both the infrastructure costs (e.g. maintenance and capital costs) and the external costs created by transport (e.g. air pollution, noise and climate change).

A recent study by the Commission (European Commission) on transport-infrastructure charging and the internalisation of externalities provides a thorough assessment of the extent to which transport-related charges and taxes internalise infrastructure and external costs in the EU. This study concludes that there is considerable room for improvement in infrastructure charging. The study also highlights the importance of internalising externalities and other non-pricing measures to promote welfare-increasing innovation across all transport stakeholders (including manufacturers, operators, infrastructure managers, etc.).

The 'polluter-pays' and 'user-pays' principles have been reflected in the successive Eurovignette directives for road infrastructure. The latest Directive (European Parliament and Council, 2011) sets common rules on distance-related tolls and time-based infrastructure charges for heavy goods vehicles. It also allows for the application of external cost charges related to noise and air pollution.

3.2. MAIN R&I INITIATIVES

Horizon 2020, the EU R&I programme, has made available almost €80 billion of funding over 7 years (2014 to 2020), in addition to the private and national public investment that this money attracted. Horizon 2020 has three priority areas: excellent science, industrial leadership and societal challenges.

Horizon 2020 mainly included transport infrastructures under the third priority heading of 'societal challenges'. This third priority featured a number of challenges, one of which was 'smart, green and integrated transport', which was also mostly related to transport infrastructure. Other third-priority challenges linked to transport infrastructure include: 'Secure, clean and efficient energy', 'Climate action, environment, resource efficiency and raw materials' and 'Secure societies - protecting freedom and security of Europe and its citizens'.

The second priority of 'industrial leadership' supports ground-breaking technologies also used for the benefit of transport infrastructure such as information and communication technology (ICT), and key enabling technologies (such as advanced manufacturing and materials, etc.).

The Joint Research Centre (JRC) published a report in January 2019 (Gkoumas et al. 2019a) focusing on R&I in bridge maintenance, inspection and monitoring in Europe in the last 25 years. The report highlights the weak link between research on bridge safety (including case studies) and adoption of bridge-safety technologies. This weak link is in spite of the large amount of research funded through FPs that addressed all areas of bridge safety (materials, loads, hazards, management, monitoring etc.). New technologies to monitor the structural health of bridges are now emerging, technologies which could potentially reshape the field of bridge inspection and monitoring.

A JRC report published in March 2019 on R&I capacity in transport infrastructure (van Balen et al. 2019) provided insights into the capacity of transport infrastructure R&I across Europe from several perspectives: (i) the FPs; (ii) the geographical and organisational distribution of funds; (iii) investments by Member States; and (iv) investments in the different modes of transport. The report is based on the database of the Transport Research and Innovation Monitoring and Information System (TRIMIS).

A follow-up TRIMIS report published in September 2019 (Gkoumas et al. 2019b) provides a comprehensive analysis of R&I in transport infrastructure. This follow-up report critically addresses research by thematic area and technology, highlighting recent developments and future needs. Major findings from this report are set out in the bullet points below.

- Under the FP7 and H2020, more than €1.06 billion has been invested in infrastructure research projects to date. This includes €701 million of EU funding and €360 million of own contributions by beneficiary organisations. The total investment under FP7 was €563 million, and €499 million has been invested so far under H2020. This amount is likely to grow as several funding calls have yet to be launched.
- Spending on transport infrastructure research under the H2020 research FP has increased over time. Road and rail research attracted the greatest share of infrastructure funds. Research on airport infrastructure is comparatively small, and research on waterborne transport is very limited. Remarkably, aviation- and waterborne-related projects are also financed through other instruments (joint undertaking (JU) SESAR for instance) not covered by the report.
- The infrastructure research funds are spread across Europe, and the areas with many beneficiaries are clearly visible. There are several large beneficiaries in the UK, France, Germany and Denmark. Most organisations are located in a wide 'band' running between Manchester and Munich. Organisations from the EU-13 countries[4] received a smaller amount of H2020 transport-infrastructure research funds than organisations from EU-15 countries.
- Significant funding has been awarded to projects dealing with crisis management, including those seeking to develop standards for security of infrastructure and tools for crisis advice.
- The measurement of carbon emissions during the construction, maintenance and eventual deconstruction or recycling of infrastructure has not received much research attention. There has also been limited research into the effects of using unconventional transport systems for freight.
- Many projects conduct research into how to monitor structures to better plan maintenance. This can lead to better use of the infrastructure.

On 7 June 2018, the Commission adopted its proposal for **Horizon Europe**, a €100 billion R&I funding programme to last 7 years (2021-2027). The programme aims to: (i) strengthen the EU's scientific and technological bases; (ii) boost Europe's innovation capacity, competitiveness and jobs; (iii) deliver on citizens' priorities; and (iv) sustain European socioeconomic model and values. The second pillar of Horizon Europe 'Global challenges and industrial competitiveness' has a cluster dedicated to climate, energy and mobility.

Under Horizon 2020, public-private partnerships were set up to strengthen the financial commitment from industrial stakeholders. Whether to finance public-private partnerships with Horizon Europe funds was still a subject of discussion at the moment this roadmap was being written.

The joint undertaking **Shift2Rail** is the first European rail initiative to seek focused R&I and market-driven solutions by accelerating the integration of new and advanced technologies into innovative rail product solutions. Shift2Rail promotes the competitiveness of the European rail industry so it can meet changing EU transport needs. R&I carried out under the Shift2Rail joint

[4] Group of 13 EU countries: Bulgaria, Czechia, Croatia, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia.

undertaking seeks to develop the technologies needed to complete the single European railway area. Shift2Rail is supported by €450 million of H2020 funds and by €470 million from industrial stakeholders.

The Shift2Rail activities most related to infrastructure are carried out in Shift2Rail's Innovation Programme 3 (IP3) 'Cost-efficient and reliable infrastructure'. The IP3 activities are mainly oriented towards specific components of rail infrastructure. This is because the European railway network was incrementally developed over many decades, generating a patchwork of components, sub-systems and localised improvements. Many railway networks are non-optimised and susceptible to performance issues due to this legacy. The infrastructure activities targeted in IP3 are:

- switches and crossings systems;
- the optimised track system and proposals for the next generation track system;
- the bridges and tunnels assessment – repair and upgrade;
- intelligent asset management of the infrastructure by information management, integrated measuring, and monitoring;
- the drawing up of intelligent asset-management strategies;
- the intelligent management of energy by development of concepts for the railway smart grid;
- turning railway stations into multimodal hubs.

SESAR and its master plan

As the technological pillar of Europe's ambitious single European sky (SES) initiative, SESAR is the mechanism which coordinates all EU research and development activities in air-traffic management (ATM). The SESAR joint undertaking was set up in 2007 to manage this large-scale and international public-private partnership between the European Commission and industry stakeholders.

The SES initiative stated in 2005 with aspirational high-level goals to: (i) enable a threefold increase in capacity; (ii) reduce delays both on the ground and in the air; (iii) improve safety by a factor of 10; (iv) enable a 10% reduction in the impact of flights on the environment; and (v) provide ATM services to airspace users at a cost at least 50% lower than at present. A performance-driven and technologically-enhanced ATM system is a critical element for achieving greater connectivity and ensuring the sustainability of aviation in Europe and in the world. A focus on ATM also means focusing on airports as essential elements of air-traffic management.

The European ATM master plan is a planning tool to set ATM priorities and to ensure the achievement of SESAR targets. Its purpose is to outline the vision and performance ambitions for future ATM systems up to 2035, and to formulate an outlook towards 2050. It also prioritises research and development activities, as well as the subsequent solutions required to achieve these objectives.

The R&I programme of the **Fuel Cells and Hydrogen 2 joint undertaking (FCH 2 JU)** is structured around two R&I pillars dedicated to transport and energy systems. The transport pillar encompasses all aspects of hydrogen use in transport, including fuel-cell electric vehicles (FCEVs) as well as rail, maritime, and aviation applications. The FCH2 JU includes research on the essential hydrogen refuelling infrastructure for these vehicles and systems. FCH 2 JU supports the 'European hydrogen refuelling station availability system' initiative, which seeks to: (i) create a real-time information system on the availability of hydrogen refuelling stations in Europe; and (ii) overcome the challenges preventing the uptake of FCEVs.

FCH2JU's second pillar is the energy pillar. The energy pillar will support projects in four areas set out below.

i. Hydrogen production for (i) energy storage and (ii) grid balancing from renewable electricity. This includes large-scale 'green' hydrogen production, storage and re-electrification systems. The initial focus will be on the role that hydrogen can play in the integration of renewable energy sources into the grid.
ii. Hydrogen production with a low-carbon footprint from other resources – different hydrogen pathways will be developed and, if appropriate, demonstrated.
iii. Fuel-cell systems for combined heat and power and for power only – covering the technical developments necessary to reduce costs, increase lifetimes, and improve performance.
iv. Hydrogen storage, handling and distribution – to allow the storage of hydrogen at central production plants and distribution to customers.

COST actions

European Cooperation in Science and Technology (COST) is a funding organisation for the creation of research networks, called COST actions. These networks offer an open space for collaboration among scientists across Europe (and beyond), and thus give impetus to research advancement and innovation. COST actions have also funded research in transport infrastructure.

During the 7th EU FP, COST actions allowed the interconnection of €5 billion in national research and technology projects with a COST investment of €250 million. Although most COST actions are not directly associated with improving transport infrastructure, there were actions specifically aimed at: (i) quantifying the value of structural health monitoring for roadway bridges at European level; and (ii) standardising quality specifications for roadway bridges at European level.

LIFE – EU financial instrument supporting environmental, nature-conservation and climate-action projects

The LIFE programme, created in 1992, is the EU's funding instrument for environment and climate action. The current funding period from 2014 to 2020 has a budget of €3.4 billion. The programme has two sub-programmes: environment, covering nature-conservation projects; and climate, covering areas such as renewable energy, energy efficiency and farming/land use.

CEDR

The main goal of the **CEDR** (Conference of European Directors of Roads) is to promote innovation activities through collaborative transnational innovation programmes of CEDR members via the CEDR's annual research call. During 2017 and 2018, several calls for projects were launched on: building-information modelling; automation; new materials (techniques, methods), noise and nuisance; collaborative planning of infrastructure networks; and spatial developments.

FEHRL

The CEDR is supported by **FEHRL**, which is made up of national road research institutes nominated by their respective national road administration or ministry. The FEHRL has members from 32 countries. The FEHRL's primary objective is to create an environment for identifying research priorities and promote a positive climate for cooperation between its institutes. The FEHRL promotes and facilitates collaboration on road research, and provides high-quality information and advice on technologies and policies related to roads.

CEF

Transport infrastructure is also significantly supported by projects financed with **CEF** funds. The CEF is a key EU funding instrument designed specifically to: (i) address missing links and bottlenecks; and (ii) directly invest into European transport (trans-European transport networks, TEN-T), energy (trans-European energy networks, TEN-E) and digital infrastructures (broadband and information and communication technologies, ICT).

CEF is the funding instrument for achieving the goals of European transport infrastructure policy. CEF supports investments in building new transport infrastructure or rehabilitating and upgrading existing infrastructure. The CEF facilitates the implementation of R&I results on infrastructure.

CEF can also support innovation in the transport system to: (i) build and improve the use of infrastructure; (ii) reduce the environmental impact of transport; (iii) enhance energy efficiency; and (iv) increase safety.

More detailed information about the programmes and projects financed with EU funds can be found at TRIMIS.

3.3. ROADMAPS, CROSS-MODAL PROGRAMMES AND NATIONAL PROGRAMMES

The main technology platforms for transport infrastructure have developed research roadmaps and strategic research agendas. An overview is given in Annex 1 for these platforms, which are:

- ACARE, the Advisory Council for Aviation Research and Innovation in Europe;
- ALICE, the Alliance for Logistics Innovation through Collaboration in Europe;
- ECTP, the European Construction, built-environment and energy-efficient building Technology Platform to promote the future of the built environment;
- ERRAC, the European Rail Research Advisory Council;
- ERTRAC, the European Road Transport Research Advisory Council;
- Waterborne, the European R&I platform for waterborne industries.

Annex 1 is complemented with information about the contributions from:

- the REFINET coordination and support action (CSA);
- the CSA projects, USE-iT (Users, Safety and security and Energy in Transport Infrastructure) and FOX (Forever Open Cross (X) modal infrastructure);

Annex 1 also refers to:

- relevant activities by the OECD and International Energy Agency (IEA);
- two cross-modal research programmes that financed research projects in conjunction with some Member States: the ERA-NET Plus Infravation and infra4Dfuture (i4Df).

During the creation of this roadmap, the expert group developed a survey with Commission support to gather input for the drafting of the current infrastructure STRIA roadmap. In this survey, some Member States gave an overview of their strategies for transport infrastructure and also gave information about their specific research programmes and activities. A synthesis of the information from this survey is given in Annex 1.

4. MAIN CHALLENGES

Efficient transport services and infrastructure are vital to: (i) make the most of the economic strengths of all regions of the European Union; (ii) support the single market and growth; (iii) enable economic and social cohesion; and (iv) influence competitiveness. User needs and environmental issues should also be taken into account.

As stated in the 2011 white paper on transport, the main challenges for the transport sector in the EU include: (i) creating a well-functioning competitive single European transport area; (ii) connecting Europe with modern, multimodal, safe and secure transport infrastructure networks; and (iii) shifting towards environmentally friendly mobility. The Horizon 2020 research programme focuses on developing transport infrastructure that can support 'smart, green and integrated transport'.

4.1. HOLISTIC CHALLENGES TO TRANSPORT INFRASTRUCTURE

Global transport infrastructure faces five main 'mega' challenges, set out below.

i. EU competitiveness – a level playing field in Europe and globally.
ii. Safety and security as a priority for users' needs.
iii. Digitalisation, big data and smart infrastructure to ensure global connectivity.
iv. Environmental protection, including decarbonisation, reduction of emissions and protection of energy supplies.
v. Urban transport infrastructure to ensure efficient and safe urban mobility

4.1.1. EU competitiveness – a level playing field in Europe and globally

One of the major challenges faced by transport in the EU is how to make the EU competitive. This means not only ensuring the required capacity and full integration between transport modes, but also expanding the EU's industrial leadership globally. Intermodality, interoperability and integration of transport systems are therefore all of great importance.

The EU has recently been suffering from low levels of investment in transport infrastructure. To maintain competitiveness, this trend of low investment needs to reverse. Better coordination is needed between EU countries on cross-border infrastructure projects.

For some EU countries, the main priority is to upgrade and maintain existing infrastructure. Other countries need to develop or expand their transport network. The availability and quality of transport infrastructure are particularly low in the eastern part of the EU, whereas in the western and southern parts of the EU, the existing infrastructure urgently needs maintenance. In addition, there are specific needs and requirements for ultra-peripheral regions, which are also part of the EU, but frequently suffer from problems such as a lack of accessibility, different climate conditions, etc.

The challenges for both freight and passenger transport systems include: (i) designing infrastructure and operating them around customer needs; (ii) developing customer-centric transport to overcome the lack of coordination; and (iii) making intermodal transport work. The TEN-T network requires investment in new infrastructure, refurbishment, modernisation, and life-cycle optimisation.

One of the biggest challenges facing investment in transport infrastructure is proper governance. This means focusing on investments in existing infrastructure and only building new infrastructure when necessary. Better operational practices, combined with making full use of digital and control technologies, can often be a better solution than building new infrastructure. The use of infrastructure can be maximised with strategies such as: the promotion of autonomous vehicles; demand management; improvement of air traffic control; vessel-traffic monitoring systems; and the implementation of European rail-traffic management systems.

Passenger transport systems suffer from similar integration and intermodal challenges. This is often because networks have been developed for single modes and are not suitable for changing user needs and integration with other modes. Probably the greatest challenge for passenger transport operators is to provide much better journey planning and travel information for users in easy-to-use formats. This information will help operators and users alike to develop better processes for managing transfers between routes or modes, including providing easy payment or ticketing systems that work on a ‘pay once per trip’ basis.

There is also increasing demand for a high standard of service and proper maintenance conditions, with growing intolerance by transport users of non-availability or delays. For instance, transport systems are increasingly expected to be fully operational during severe weather events. To this demand for increased reliability is added the need to adapt infrastructure so that it can withstand more frequent severe weather events and deal with climate-change adaptation.

It is the role of governments and governance bodies to connect networks, policies and strategies at different levels (administrative, network, mode, etc.) and to develop a truly global transport policy.

4.1.2. Safety and security as a priority for users’ needs

Transport systems have been under continuous pressure to improve the safety and security of users for many years. That pressure continues, especially in road transport, where fatal and serious injuries remain a social and economic problem. Moreover, pressure is also increasing to reduce the risks faced by maintenance workers and other people working on the construction and operation of transport infrastructures.

Alongside investments in safety, the owners of transport infrastructure have also made substantial investments in security, protecting their assets against physical, chemical, biological and cyber attacks. Security is likely to be an area of increasing importance in the near future.

Dealing effectively with safety hazards and security threats requires a fundamental shift in thinking about safety and security. Today, safety and security are being addressed as an integral issue in R&I principles. This will help create synergies between the two domains for the better protection of users and assets.

As early as 2011, the white paper recognised that setting a framework for safe transport is essential for the European public. The white paper makes explicit reference to proposals such as: (i) the European strategy for civil aviation safety, the (ii) vessel-traffic monitoring and information system SafeSeaNet; and (iii) the harmonisation and supervision of safety in the single European railway area.

In addition, the white paper also set a goal that there should be near-to zero fatalities in road transport by 2050, making the EU a world leader in safety and security in all modes of transport.

4.1.3. Digitalisation, big data and smart infrastructure to ensure global connectivity

The advancement of vehicle technology is placing new demands on transport infrastructure for digitalisation, data connectivity and changing operational practices. This requires transport infrastructure to be far more flexible in use, and to adapt quickly to changes (especially changes in demand).

Growing digital connectivity enables people and freight to use transport systems in different ways, and to gain access to large amounts of real-time dynamic transport data. This can help people to manage their own use of the infrastructure (through rail or highway journey information). This growing connectivity also presents challenges to transport operators and infrastructure owners, because better real-time information enables users to plan their own alternative routes during times of congestion or disruption. This introduces additional stakeholders into transport operation.

The operation of transport infrastructure is the area most affected by digital technologies and by rapid changes in demand or service standards. Transport infrastructure needs greater operating resilience, avoiding vulnerability to single-system or component failure. This is especially true for rail systems that are intrinsically dependent on multiple critical systems.

Communication between vehicles and infrastructure, and between vehicles themselves, is also crucial to increase the safety of future automated vehicles. This will improve their full integration into the overall transport system.

On transport management systems, there have been a number of European initiatives. These initiatives include SafeSeaNet; the European Rail Traffic Management System (ERTMS); the SESAR ATM system; and intelligent transport systems for road. However, the fragmented deployment of technology and communications across EU countries creates challenges for these transport management systems. This fragmentation creates barriers within the single

market and can hamper interoperability between different electronic systems and technological standards.

Intelligent transport systems for road transport have the potential to improve road efficiency and make mobility safer. However, their implementation is sometimes complex in local road networks, due to the relatively high cost of installation and management. Uncertainties about the speed at which vehicle automation will develop mean that infrastructure owners struggle to plan investments with confidence.

For rail, the deployment of ERTMS is the foundation for a progressively more automated interconnected railway system. The development of 'game changers' are key for delivering more flexibility in operation and better real-time adaptation to the demand. These 'game changers' include the next generation communication system, automatic train operations, and satellite positioning. They can lead to higher capacity and thus improved economic competitiveness, although this higher capacity will require more resilient infrastructure. The ERTMS research is focused on reducing ERTMS costs for the transition from legacy systems to more resilient and higher-capacity infrastructure.

For travel over land, the next generation of telecommunication solutions will be key to transforming how vehicles relate to infrastructure and to other vehicles.

4.1.4. Environmental protection, including decarbonisation, emission reductions, and protection of energy supplies

The governance of transport infrastructure must ensure that the principles of the energy union are compatible with mobility, economic growth, employment and competitiveness. Cooperation between the public and private sectors in transport is usually focused only on the operational performance of the transport service. But good governance of public and private sector participants should also focus on promoting environmentally friendly modes of transport and the reduction of transport emissions.

The adaptation of infrastructure to new mobility patterns, and the deployment of infrastructure for clean alternative fuels poses additional challenges. These additional challenges require new investments and a different approach to the design of transport networks and business models.

A global challenge is to achieve a 60% reduction in GHG emissions from transport by 2050 (compared to the base year of 1990). GHG emissions measured over a piece of infrastructure's entire life-life-cycle are not routinely considered at the planning stage for new infrastructure, and are rarely considered when it comes to upgrades of existing infrastructure. The infrastructure-design phase often considers GHG emissions only for construction. The carbon intensity of operation, maintenance and eventual decommissioning are not routinely considered. There is often a view that infrastructure designers can do little to influence the overall emissions from the operation phase of the infrastructure. Methodologies are needed to support the most efficient use of the money obtained from infrastructure charges, and to incentivise measures aimed at promoting greener mobility.

Transport governance must address not only emission reductions, but also noise, waste production, protection of the environment, accidents, etc.

4.1.5. Urban transport infrastructure to ensure efficient and safe urban mobility

Almost three quarters of the European population lived in an urban area in 2015 (Eurostat, 2016). Approximately two thirds of the world's population will be living in an urban area by 2050 (United Nations, 2018). Improving urban mobility while reducing congestion, accidents and pollution is therefore a common challenge facing all major cities. The Commission supports these goals, and in 2013 put forward the urban mobility package, which included proposals for relevant action at local, Member-State and EU level.
Modern technologies have the potential to transform urban areas into cleaner, safer and more efficient places, also known as smart cities. Two essential preconditions for this paradigm shift are connectivity and sufficient infrastructure development.

The most significant transport challenges are often related to urban areas and arise when transport systems cannot satisfy urban mobility requirements. European cities increasingly face problems caused by transport and traffic. The question of how to improve mobility while at the same time reducing congestion, accidents and pollution is a common challenge shared by all major cities in Europe.

The concentration of economic activities in large cities makes the smart management of transport systems necessary. Urban productivity is highly dependent on the efficiency of its transport system in moving passengers and freight.

Congestion is one of the most pressing problems in urban areas. Another problem is the inadequacy of public transport and the lack of consideration for non-motorised transport in the physical design of infrastructures and facilities.

An additional factor is the high costs of infrastructure maintenance. Cities are facing growing infrastructure maintenance costs and pressure to upgrade to more modern infrastructure.

4.2. MAIN CHALLENGES FACING INFRASTRUCTURE FOR EACH OF THE TRANSPORT MODES

This section lists the main challenges facing the infrastructure of different transport modes. The list complements the challenges already referred to above.

Each of the 'mega' challenges summarised in the previous chapter may have some specific aspects requiring research within individual transport modes.

4.2.1. Challenges for multimodal transport infrastructure

A major challenge is to holistically deal with transportation, ensuring efficiency, reliability, and environmental sustainability. Future investments should be focused on connecting and optimising the different transport modes.

The following challenges have been identified for multimodal transport.

- ✓ Increasing transport flows and supporting mobility while reaching the 60% GHG emission reduction target.

- ✓ Developing and deploying infrastructure for new and sustainable fuels and propulsion systems.
- ✓ Optimising the performance of multimodal logistics chains, increasing the use of more energy-efficient modes.
- ✓ Increasing the efficiency of transport and infrastructure use with information systems and market-based incentives.
- ✓ Managing long-distance travel and intercontinental freight.
- ✓ Ensuring secure and safe transport.
- ✓ Introducing innovative technologies.

4.2.2. Challenges for road transport

Road transport is the dominant mode for passenger and freight transport in terms of traffic volumes. It is also facing an increasing number of challenges. It is crucial to create safe and reliable roads while simultaneously reducing emissions. Many roads are also ageing and there are limited budgets for maintenance and upgrades.

Another significant challenge for European competitiveness is to improve road traffic management and cooperative intelligent transport systems (C-ITS) in Europe. This will play a crucial role in enabling fully automated driving functionalities.

The following challenges have been identified for road transport:

- ✓ Building roads that are economically, socially and environmentally sustainable (this means ensuring that there are funds available for the proper maintenance of roads to better provide a quality service for all road users).
- ✓ Ensuring road safety, with a particular focus on vulnerable road users and adaptation of roads to an ageing population.
- ✓ Ensuring security, highlighting the role of roads in emergencies (e.g. for rapid evacuation and assistance).
- ✓ Adapting roads to climate change by improving their resilience;
- ✓ Introducing smart and fair road charging.
- ✓ Reducing the impact of roads on the environment, including GHG emissions, throughout the life-cycle.
- ✓ Reusing and recycling materials.
- ✓ Improving roads to provide services to vehicles that are powered with alternative sources of energy.
- ✓ Automated roads: integrating technology and communication networks to provide new services based on data and digitalisation.
- ✓ Planning infrastructures according to objective technical and social parameters and needs.
- ✓ Improving the capacity to reduce congestion, while avoiding costly large investments in enlarging infrastructure.
- ✓ Enabling best practices in operation and management.
- ✓ Providing high-quality infrastructures for public transport services.

4.2.3. Challenges for rail transport

The global challenges of rail transport are to integrate digitalisation in the overall system; to transform rail transport towards global automation; to integrate new mobility solutions; and

to provide more sustainable solutions. Addressing these challenges will require modern, efficient and reliable infrastructure.

The following specific challenges are identified for the railway mode.

- ✓ Increasing digitalisation. A fully connected and integrated digital railway is the foundation for efficient transport of passengers and freight. A resilient and powerful telecommunication network is an essential condition for this digitalisation.
- ✓ Accelerating the automation and development of artificial intelligence. Real-time management of rail operations increases flexibility in the operations, capacity and resiliency of the system. This makes it possible to sometimes avoid infrastructure investments.
- ✓ Developing sustainable solutions. Connected and holistic energy-management systems support more sustainable mobility solutions. Societal demands are met by environmentally friendly solutions (e.g. reduced noise, reduced vibration, reduced emissions, and alternatives to diesel).
- ✓ Increasing cost efficiency. The digitalisation of engineering, operations and maintenance activities drives reductions in the overall cost of the system.
- ✓ Offering a 'fast track' so new technologies and innovations can quickly come to the market. It is essential that innovation be quickly deployed and implemented by more efficient bottom-up standardisation mechanisms and simplified regulations.
- ✓ Proposing new mobility solutions for which modal integration is matched and facilitated by developments in stations and terminals that turn them into 'mobility hubs'.

4.2.4. Challenges for waterborne transport

The biggest challenge in waterborne transport is to build effective, reliable, integrated and well connected waterborne systems.

The following challenges have been identified for waterborne transport.

- ✓ Integrating shipping and inland navigation into seamless port and logistics operations.
- ✓ Ensuring zero emissions from inland navigation vessels by 2050.
- ✓ Dealing with insufficient port capacity and efficiency.
- ✓ The deployment of smart shipping.
- ✓ Addressing the need for comprehensive and interoperable flows of digital information.
- ✓ Building smart port infrastructure that is well connected to other modes of transport.
- ✓ Creating a network of multimodal transport corridors connecting industrial, peripheral, and island areas with modern transhipment facilities.
- ✓ Innovating, including the use of advanced technologies and the monitoring of automation trends.
- ✓ Ensuring safe, competitive and eco-friendly shipyards and production sites.
- ✓ Ensuring the sector has zero accidents, zero loss-of-life and zero pollution, while ensuring cybersecurity.

4.2.5. Challenges for air transport

A performance-driven and technologically-enhanced ATM system is critical for achieving greater connectivity and ensuring the sustainability of the aviation sector in Europe.

Advanced technologies are revolutionising the business landscape. European aviation needs to embrace this change and further engage in its digital transformation based on data, connectivity and automation.

The future European ATM system also relies on the full integration of airports as nodes in the network. This integration means that airports must improve runway efficiency; create more accurate navigation and ground-routing tools; and further integrate airport operations within the wider transport network.

The following challenges have been identified for air transport:

- ✓ Dealing with the emergence of new competitors and services.
- ✓ Developing the four-hour ‘door-to-door’ concept, including by addressing ‘landside’ congestion in airport infrastructures.
- ✓ Addressing possible capacity problems in major EU airports in the near future.
- ✓ Better strategic airport planning at EU level; master plans for key airports in Member States, according to common best practices.
- ✓ Improving the single European sky area
- ✓ Creating an integrated and optimised air traffic management system.
- ✓ Improving multimodal connections at airports and within airport infrastructure.
- ✓ Improving connectivity within the EU and worldwide.

- ✓ Combining effective security measures with methods/technologies that facilitate passenger flows at airports and minimise inconvenience/delays.
- ✓ Addressing cybersecurity and cybersafety risks.
- ✓ Incorporating green technologies, including biofuels.
- ✓ Improving resilience.
- ✓ Managing and harmonising noise-related operating restrictions at EU level.
- ✓ Digitalisation.
- ✓ Adopting novel concepts and solutions to help airports address the environmental and societal concerns of neighbouring communities.

4.2.6. Challenges for urban mobility

Large cities face various problems preventing the emergence of efficient and effective urban mobility. City infrastructure should be redesigned to become sustainable and future-oriented with its mobility systems.

The following challenges have been identified for urban mobility.

- ✓ Considering cities as part of large global mobility systems.
- ✓ Introducing smart transportation for smart cities.
- ✓ Integrating urban-traffic-management and mobility-information systems; increasing public-transport capacity and efficiency by: (i) providing door-to-door mobility-information and guidance systems; and (ii) facilitating intermodal travel chains.
- ✓ Managing urban logistics and delivery services: smart mobility services are necessary to avoid unnecessary vehicle movement in urban areas. This will make it necessary to develop shared data, infrastructure and logistics business models for the distribution of urban goods.
- ✓ Promoting carpooling and ridesharing services.
- ✓ Ensuring the shared use of physical infrastructure (e.g. off-peak use of underground or light-rail passenger networks for goods distribution).
- ✓ Shifting as much of the car fleet as possible from gasoline and diesel cars towards alternative fuels.
- ✓ Adopting stricter emission standards.
- ✓ Promoting innovative operation models: publicly owned and operated systems must work in tandem with services that are privately owned and run.

5. PRIORITIES FOR RESEARCH & INNOVATION IN TRANSPORT INFRASTRUCTURE

The main challenges described in the previous chapter summarise the essential improvements needed to fulfil the goal of STRIA. Those challenges mostly involve the deployment and management of transport infrastructure, and many of them should be addressed in coordination with the other STRIA roadmaps.

The STRIA roadmap was created to bring consistency, direction and interoperability to the various topics that will be proposed for R&I.

The priorities for R&I identified in this roadmap are divided into the following thematic areas:

A. governance;
B. life-cycle and asset management;
C. financing, pricing and taxation;
D. technology and digitalisation;
E. multimodality, interoperability and interconnectivity;
F. safety and security;
G. sustainability, environment and resilience;
H. logistics.

This roadmap could be used as a working document by different responsible authorities (e.g. the European Commission, Member States, industry, etc.) and for future coordination with the other STRIA roadmaps.

For each thematic area, a set of topics and actions is proposed, classified under policy actions (P), management actions (M) and technological actions (T).

After the description of topics and actions for each thematic area, a group of additional actions is presented, identifying transversal/cross-cutting activities. These activities are key for the proper performance of transport infrastructures.

5.1. THEMATIC AREA A: GOVERNANCE

Governance refers to the structures and decision-making processes that allow a state, organisation or group of people to conduct its affairs (World Economic Forum, 2016). For EU transport policy, governance should be regarded as the set of processes and results that, taking different public and private stakeholders into consideration, seeks to achieve set goals.

Because transport infrastructure is often large-scale and expensive, public investment decisions are usually made at a political level as they impact on the lives of communities. This political involvement can be problematic, as infrastructure facilities must be planned for the long term, while political decisions, electoral terms, and public opinion are frequently short-term oriented. A further layer of complexity is added by infrastructures owned by private bodies, which also play a role in the global mobility system.

Planning is a key process for transport infrastructure. Demographic changes, the densification of cities, growing complexity in transport, and new stakeholders in the mobility sector will increase competition for space. This competition takes place not only on the surface, but also below ground and in the skies above. A new holistic and comprehensive approach to spatial planning should therefore be developed, with new methodologies and tools for decision-makers.

This thematic area includes the following topics and actions.

TOPIC	**Planning**		
Why is this a priority?	Innovation is needed to strengthen transport planning and delivery within and across regional and state boundaries. This planning includes both strategic network planning and operational-level planning. More effective governance will support investment in better quality (and better value for money) transport links as part of a new, holistic and comprehensive approach to spatial planning.		
Actions	A.1.	Plan infrastructures according to national, European and world mobility needs, with a cross-modal perspective from an early stage, and taking into consideration infrastructure as a generator of regional and national development and cohesion.	P
	A.2.	Develop infrastructure for public transport systems and soft modes, such as walking or cycling, to make mobility systems more attractive and environmentally friendly (e.g. reserved lanes).	P/T
	A.3.	Optimise methods to better take into consideration users' expectations and travel trends in planning procedures. These methods might be based on the use of big data, artificial intelligence and other technologies.	M/T
	A.4.	Analyse the relationship between spatial planning and transport infrastructure, as a base for optimised mobility solutions.	P/M
	A.5.	Develop and use simulation, planning tools, assessment methods and consultations to support project prioritisation and evidence-based decision-making during the infrastructure life-cycle.	T

TOPIC	**Legal framework and regulations**		
Why is this a priority?	Changes in mobility frequently imply changes in transport infrastructure. This may require updates to the legal framework and regulations. Research may be required before these updates can be made.		
Actions	A.6.	Identify regulatory incentives and barriers which are relevant for a more efficient construction, upgrade and use of infrastructure, avoiding isolated solutions.	P/M

TOPIC	Procurement		
Why is this a priority?	Procurement is the basis for the provision of services and goods, especially when private stakeholders are involved.		
Actions	A.7.	Ensure the implementation of a legal framework for incentives and penalties in procurement processes. Promote innovative and optimal solutions and reinforce the integrity and transparency of the process, ensuring best value for money from a societal perspective.	P
	A.8.	Foster green public procurement (particularly focused on the reduction of emissions, recycling and climate adaptation and mitigation) and innovative public procurement of transport infrastructure.	P
	A.9.	Implement contractual performance indicators to improve the operation of transport.	P
	A.10.	Strengthen capabilities for preparing and conducting public procurement of transport infrastructures. Foster the early participation of all relevant stakeholders in the preparation and procurement of EU funded large-scale infrastructures.	P

TOPIC	Standardisation		
Why is this a priority?	The EU has an active standardisation policy that promotes standards as a way to better regulate and improve the competitiveness of European industry. Standards support market-based competition, create a level playing field, and help ensure the interoperability of complementary products and services, all of which are essential for transport infrastructure. Standards can also facilitate the take up of technical innovations.		
Actions	A.11.	Improve and create standards for transport infrastructures and data aggregation in a new mobility framework.	P

5.2. THEMATIC AREA B: LIFE-CYCLE AND ASSET MANAGEMENT.

Although in some Member States there is a large and extensive network of transport infrastructure, there are other European regions where it is still necessary to build much of this infrastructure. During construction, it is very important that the proper governance requirements are met, in order to comply with construction timeframes and quality standards. The level of innovation of the construction industry must increase in the coming years. Recent initiatives on reuse and recycling should be extended, and more focus should be put on using new materials and processes in construction.

It is essential to focus on project delivery in the construction of a piece of transport infrastructure. In the construction phase, cooperation among different stakeholders is a priority, and innovation must play a significant role, not only in terms of technology deployment, but also in terms of subsequent checks and follow-up.

In addition, although building new infrastructure ranks high on political agendas, operations and maintenance can be low priorities. This means that operations and maintenance often suffers from a disproportionate shortage of funding. This can result in short-term deteriorations in performance and, in extreme cases, to accidents and the loss of human life. In the long term, this drop in funding for operations and maintenance can lead to higher total costs for heavy repair or rebuilding.

Infrastructure is frequently underfunded when it comes to maintenance and life-extension activity. It is relatively common for infrastructure not to receive the necessary maintenance and regeneration work (or for it to be replaced if necessary). In addition, these important activities of maintenance and life extension are not included in EU-financed programmes, and are scarcely mentioned in EU transport strategies.

Many owners of transport infrastructure recognise the importance of optimising the cost of infrastructure over the full life-cycle. However, few owners are in a position to manage costs over a piece of infrastructure's full operational life. For those who do have some capacity to plan the whole life-life-cycle cost, there are often short-term pressures of affordability or programme time that drive decisions that are suboptimal in the short term.

New infrastructure is also easier to deliver than a large-scale upgrade of existing infrastructure. Nevertheless, there has recently been a rise in the popularity of modern asset-management theories and systems. Coupled with the commercial availability of low-cost tools to monitor asset performance, this has enabled innovative construction technologies to appear, enabling longer intervals between maintenance interventions. New approaches are also supporting the adoption of more predictive maintenance, offering less disruption to users. This move towards 'condition-aware' infrastructure, a concept that is in its infancy on the transport infrastructure market today (the concept is more developed for complex infrastructure like rail), is recognised as offering large financial and environmental benefits.

This thematic area includes the following topics and actions.

TOPIC	**Use of new construction processes and materials**		
Why is this a priority?	Advances and innovation are required in the transport sector, which needs to implement new procedures and technologies to achieve current EU sustainability objectives. This can be achieved by improving cooperation between the modes.		
Actions	B.1.	Use more sustainable materials and promote advanced features, such as self-healing materials.	M
	B.2.	Promote advanced and novel construction methods that include modularisations and smart concepts, facilitate automated solutions, and ensure adaptation to the new demands with low-intrusive, fast and cost-efficient infrastructure. Optimise production techniques for the prefabrication of infrastructure elements.	M/T

TOPIC	Reutilisation and recycling – circular economy[5]		
Why is this a priority?	Solutions should be developed to standardise circular economy principles for the construction of transport infrastructure. Many reutilisation and recycling activities are already in place and should be promoted worldwide. The EU should have a leading role in this promotion.		
Actions	B.3.	Develop policy guidelines to promote circular economy for transport infrastructure during its whole life-cycle, including decommissioning, highlighting the reuse of materials.	P
	B.4.	Analyse the improved emission efficiency of infrastructure reuse and the potential for greater cost efficiency.	P

TOPIC	Maintenance and regeneration as a strategic policy		
Why is this a priority?	Infrastructure maintenance should be considered as a strategic policy and should receive the required funding. This will increase the lifetime value, performance, resilience, utility and safety of transport infrastructure.		
Actions	B.5.	Introduce new contractual performance indicators, regulatory and public procurement models and incentives to maintain and upgrade infrastructure.	P
	B.6.	Promote synergies so that maintenance operations in transport infrastructure go hand in hand with greater resilience of the infrastructure.	P/M
	B.7.	Develop new methods for the maintenance and upgrade (predictive and preventive) of transport infrastructure in order to improve safety, availability, climate resilience and environmental impact, achieve cost optimisation, and develop new solutions to accommodate connected mobility.	T

TOPIC	Project delivery/implementation phase		
Why is this a priority?	The project-delivery phase is the most capital-intensive phase of an infrastructure project's life-cycle. Although this phase is short compared to the life span of the project, it has pivotal importance for the business case and for securing value for money.		
Actions	B.8.	Implement project control and risk management tools and technologies, including artificial intelligence, big data, etc. that enhance accountability and support the achievement of the project objectives.	P/M
	B.9.	Promote a platform for closer cooperation and exchange of information and data between the project owners, infrastructure operator, funding bodies, etc.	M/T

[5] In a circular economy the value of products and materials is maintained for as long as possible; waste and resource use are minimised, and resources are kept within the economy when a product has reached the end of its life, to be used again and again to create further value.

TOPIC	Asset management		
Why is this a priority?	Investment policies usually focus on infrastructure building, while asset monitoring and maintenance policies are frequently disregarded. Improving the management of transport infrastructure is essential for providing a better service and extending the life of the infrastructure. This allows new functions to be introduced while simultaneously increasing resilience.		
Actions	B.10.	Increase the ability of infrastructure to adapt faster to new developments (e.g. innovative transport means and technologies) and rapid changes in demand.	P
	B.11.	Implement a wide vision for asset management at national level (corridor and network management instead of particular elements) and across borders.	P
	B.12.	Use existing capacity more efficiently by maximising the utilisation of assets for transport infrastructure and systems.	M
	B.13.	Conduct a predictive analysis of capacity crunch within each transport mode, taking into account multimodal transport.	M
	B.14.	Integrate and upgrade information systems and remote sensing to ensure the proper decision-making process on prioritisation of asset operations and maintenance.	M/T
	B.15.	Develop the asset management of multi-use infrastructure in order to improve the safety and capacity/performance of transport infrastructure and ensure better maintenance while at the same time improving sustainability and climate resilience.	T

5.3. THEMATIC AREA C: FINANCING, PRICING AND TAXATION

A well-functioning transport network requires substantial resources across its entire life-cycle. The 2011 white paper said that the cost estimates for EU infrastructure development needed to meet the demand for transport was more than €1.5 trillion for 2010-2030. By 2030, the completion of the TEN-T core-network corridors alone will require approximately €750 billion worth of investment, with contributions from the EU and Member States.

With these figures in mind, financing is unquestionably one of the main challenges for transport infrastructures in the future, and could be a key bottleneck if it is not properly addressed.

'Smart pricing' was also included in the strategy of the 2011 white paper, which encourages policymakers to focus on the wider application of the 'polluter-pays' and 'user-pays' principle.

For all transport modes, the cost of providing transport infrastructure is met either directly through user charges or indirectly through taxation. In closed systems (rail and aviation), users pay for the infrastructure as a part of their overall transport charge, although there are different forms of subsidies. For open systems, primarily road transport, there is either no direct infrastructure charge, or the infrastructure charge is levied directly to the user in the form of a toll or tax. Many road users are also charged through the high taxes associated with vehicle ownership, fuel, etc.

Pricing has traditionally been acknowledged as one of the most effective incentive mechanisms to encourage users to take decisions that promote wider social interests. , although it has significant political and social concerns. The European Union policies in this

field are various: energy taxation, emission trading systems, "Eurovignette Directive", publication of a handbook which outlines a model for the internalization of external costs, etc; but there are still some areas to focus on research.

This thematic area includes the following topics and actions.

TOPIC	**Value for money**		
Why is this a priority?	One of the main concerns of public investment is the need to guarantee the best value for the money spent. The benefits of infrastructures should be considered at local, regional, national and European mobility levels.		
Actions	C.1.	Implement a standardised methodology for a cost-benefit analysis including decarbonisation objectives, as well as other externalities, for all transport infrastructure projects, during the whole life-cycle.	P
	C.2.	Analyse diversified infrastructure funds with earmarked and multiple sources of financing (public investment, fuel taxes, user charges, savings) and some cross financing from taxes and revenues.	P
	C.3.	Increase the amount and quality of data used for cost-benefit analysis during the life-cycle of infrastructures, using different technologies and benchmarking techniques.	M/T
	C.4.	Model the impact of the level of investment in transport infrastructure from a holistic perspective (considering all economic, social, environmental and other factors).	M

TOPIC	**Public-private partnership**		
Why is this a priority?	Exploring different ways of financing transport infrastructures requires the role of the private sector to be considered.		
Actions	C.5.	Explore innovative financing methods in a more efficient way; this would include the potential participation of new stakeholders, crowdfunding.	P

TOPIC	**Pricing and taxation strategies**		
Why is this a priority?	Recent initiatives on infrastructure taxation have challenged the idea of taking a single, homogeneous approach to taxation across all modes of transport.		
Actions	C.6.	Analyse the potential of a fair and efficient pricing of transport infrastructure, including emission taxation and better internalisation of external costs, across modes, in order to create a level playing field.	P/M

TOPIC	**Public awareness**		
Why is this a priority?	There is a need to promote social acceptance of charging principles, while bearing in mind that there will initially be opposition. Communication strategies are needed to promote public awareness.		
Actions	C.7.	Implement strategies for greater public awareness and acceptability towards infrastructure pricing.	P
	C.8.	Use big data and activity-based models to better understand users' reactions in order to fine tune infrastructure pricing strategies.	T

5.4. THEMATIC AREA D: TECHNOLOGY AND DIGITALISATION.

Technology is evolving rapidly, and is increasingly being used in transport infrastructure. In the future, traditional transport infrastructure strategies based on a long-term approach to infrastructure planning, investment and deployment will be replaced. In their place, there will be a more rapid approach to transport infrastructure strategies. This approach will be based on market changes, demographic shifts and responses from the transport and construction industry. These changes create tremendous opportunities for R&I, where the EU should play a leading role.

Transport infrastructure has not made uniform use of communication technologies. Although communication technologies play a large role in aviation, railway and waterborne transport, they are less present in other modes, such as road transport and light railways/tramways. It is also common for large differences to arise between the technologies used in main transport networks and those used in local transport networks. The development of artificial intelligence and big data offers new opportunities to: (i) improve the use of technology and digitalisation in transport infrastructure; (ii) improve cost efficiency; and (iii) promote other benefits throughout the infrastructure life-cycle.

This thematic area includes the following topics and actions.

TOPIC	**Smart infrastructure**		
Why is this a priority?	Smart infrastructures, enabled by technologies like the internet of things, are key for the deployment of smart mobility. Technological innovations now allow traditional infrastructures to be used in a more effective way, and for them to be operated and maintained more efficiently. This increases the inclusion of the general public within all transport modes, and contributes to high levels of safety and security.		
Actions	D.1.	Adapt infrastructure to support developments in technology so that new business models enabling smart infrastructure can be rapidly deployed.	P/T
	D.2.	Provide full interoperability across the modal chain, allowing passengers and freight to switch seamlessly between modes and across borders.	P/T

TOPIC	**Connected infrastructure**		
Why is this a priority?	Member States, industry and the Commission collaborate to achieve the EU's ambitious vision for connected and automated mobility in a digital single market. They take into consideration the interests of public authorities, cities, industry, and the general public. They also focus on cybersecurity.		
Actions	D.3.	Set up infrastructure to collect and manage information and data that can be used to monitor the performance of the infrastructure (asset utilisation rate).	P/T
	D.4.	Create added-value services based on the data collected from physical and digital infrastructure.	M/T
	D.5.	Develop, in a connected environment, of logistics hubs, parking lots and networks for future freight operations.	M
	D.6.	Identify infrastructure and equipment requirements for deploying technologies (sensors, software, systems, high performance computing, artificial intelligence, etc.) destined for autonomous multimodal transport.	T
	D.7.	Develop methods to balance the impact of new and existing technologies on the transport system and on the required infrastructure capacity.	T

TOPIC	**Digitalisation, Artificial Intelligence and Big Data**		
Why is this a priority?	New services and applications are continuously being developed using data collected from transport users, from the infrastructure itself, and from other sources. These new services and applications also make use of innovative technologies such as artificial intelligence. The use of big data and artificial intelligence introduces new risks for the protection and resilience of the infrastructure.		
Actions	D.8.	Introduce strategies for the automated construction and maintenance of infrastructure.	T
	D.9.	Use artificial intelligence (including data collection and exchange protocols and standards) to better plan and deliver transport infrastructures and manage assets.	T

TOPIC	**Automation/robotisation/remote solutions**		
Why is this a priority?	Innovation is required to optimise maintenance procedures and detect renovation needs by means of sensors, communication technologies, etc.		
Actions	D.10.	Foster smart infrastructures and condition-based maintenance (sensing and inspection combined with models for degradation and structural integrity), including the development of self-monitoring and self-healing infrastructures.	T
	D.11.	Use robotised equipment and innovative technologies (such as artificial intelligence, radar, ultrasound, inspection robots, satellite systems, etc.) to perform routine periodic maintenance, survey, inspection and monitoring or emergency works, reducing the risks and costs, while increasing the availability of infrastructure.	T

5.5. THEMATIC AREA E: MULTIMODALITY, INTEROPERABILITY AND INTERCONNECTIVITY

EU transport policy aims to promote a form of mobility that is sustainable and energy-efficient. These goals can be achieved by using multimodal transport, exploiting each mode's advantages and minimising its disadvantages. The European Commission pursues a policy of multimodality by ensuring better integration of transport modes and interoperability at all levels of the transport system.

This thematic area includes the following topics and actions.

TOPIC	**Integrated operation across modes**		
Why is this a priority?	One challenge to the development of integrated transport solutions is the lack of appropriate business and financial models that support the development of intermodal, interoperable and integrated transport systems.		
Actions	E.1.	Develop a strategy for EU transport integration, syncromodality, intermodality and interoperability, ensuring the infrastructure enables seamless interchange of freight and passengers.	P
	E.2.	Conduct an analysis of the main weaknesses and bottlenecks preventing a genuine integration, interoperability and intermodality of different modes of transport, from the customer perspective, including the optimal location and accessibility.	M
	E.3.	Perform an analysis of the requirements of multimodal hubs, in terms of infrastructures and services, for smart and seamless intermodality.	T

TOPIC	**Integration of information**		
Why is this a priority?	The growth of digital systems and mobile information means that transport users — and increasingly the transport operators themselves — demand more timely and accurate information across different transport modes.		
Actions	E.4.	Develop demonstrations and implement on a small-scale in order to show technologies and new forms of information-sharing needed to improve the integration of transport systems, address challenges for intermodal nodes, etc.	T

TOPIC	**Integration of multimodal nodes**		
Why is this a priority?	There is a pressing need to integrate multimodal transport nodes in metropolitan and urban areas. These nodes should also include multi-functional environments (energy, delivery services, tourism, water supply in the case of inland waterways, etc.). In addition, the uptake of unconventional transport systems for both freight (e.g. drones) and passengers (e.g. electric biking, automated vehicles) will make it necessary to rethink intermodal nodes.		
Actions	E.5.	Include transport infrastructure optimisation in sustainable urban mobility plans, for all modes and multi-functional environments.	P
	E.6.	Perform modelling of inland waterways / port-city opportunities and integrate water freight & passenger solutions into new forms of mobility.	T

5.6. THEMATIC AREA F: SAFETY AND SECURITY.

Safety and security are of primary concern for any transport system, so they should be at the heart of the whole life-cycle of infrastructures. The Commission has the role of responding to the safety and security expectations of users by ensuring high standards for safety and security in all modes of transport.
This thematic area includes the following topics and actions:

TOPIC	**Reducing risks by integrating safety as a priority in the whole life-cycle of transport infrastructures.**		
Why is this a priority?	Safety should be a starting point in the planning, design, construction, operation and maintenance stage of all transport infrastructures. In addition, the evaluation and management of safety has to evolve by, among other aspects, integrating the overall potential benefits of digitalisation.		
Actions	F.1.	Maintain high EU safety and security standards, by implementing and following up on risk and performance indicators for all transport infrastructures, including across borders.	P
	F.2.	Develop smart tools for predictive assessment and real-time monitoring of safety risks and system effectiveness of infrastructure.	P
	F.3.	Utilise cost-effectiveness analysis when analysing to what extent a given infrastructural solution and technologies can potentially improve safety.	P
	F.4.	Implement approaches that aim at zero accidents for all transport modes, taking into consideration all the stakeholders and including the concept of 'forgiving infrastructure', which compensates for human errors and therefore reduces the risk and consequences of accidents.	P / M
	F.5.	Develop tools for evaluating the potential effectiveness of information and communication technologies in improving safety.	M
	F.6.	Anticipate and provide solutions to emerging risks in the transition phases (e.g. highly automated vessels or vehicles in mixed road traffic) and in the shared infrastructures (e.g. mix of cars, scooters, and bikes in roads; inland and maritime shipping for passengers and freight).	T
	F.7.	Implement models of the system/sub-systems behaviour that are able to automatically assess how an asset failure affects the infrastructure systems.	T
	F.8.	Improve the management of critical interfaces between operators, modes or different countries, using advanced solutions and analysis.	T
	F.9.	Analyse concepts and procedures for introducing safety-relevant tools and methods based on artificial intelligence.	T
	F.10.	Ensure safe interaction of users with vehicles and infrastructure in the digital environment (human-machine and human-infrastructure interface).	T
	F.11.	Improve safety for workers and users in work zones.	M/T

TOPIC	Safety of vulnerable users		
Why is this a priority?	Particular attention should be paid to those users in a situation of vulnerability in relation to all the other users, taking into account their limited access to certain services or other physical / functional characteristics.		
Actions	F.12.	Develop dedicated infrastructure for vulnerable users (e.g. pedestrians and cyclists or users of small boats, but also including users of new forms of mobility such as e-scooters).	P
	F.13.	Analyse solutions to improve the safety of the elderly and disabled.	M
	F.14.	Assess users' vulnerability in terms of their lack of access to data and communication opportunities, in order to foster an inclusive, digitally interconnected transport system.	M

TOPIC	Protecting infrastructures against attacks		
Why is this a priority?	Transport security is a sensitive issue that affects all transport users and stakeholders but should not be excessively intrusive. Not only terrorist attacks, but also vandalism and robbery, piracy or other crimes should be considered.		
Actions	F.15.	Promote a cross-modal security strategy that protects infrastructure from trespass/security/terrorist threats by using devices and systems that automatically detect security breaches.	P
	F.16.	Identify critical infrastructures and critical points/sections, including across borders.	M
	F.17.	Maintain the right level of cybersecurity throughout the overall life of the infrastructure.	M/T
	F.18.	Ensure the development of maintainable innovative security solutions based on the use of technologies and security risk management.	T

5.7. THEMATIC AREA G: SUSTAINABILITY, ENVIRONMENT AND RESILIENCE.

Given the growing concerns for the environment in recent years, a number of research projects and initiatives have focused on optimising the life-cycle of transport infrastructures through labelling, the reuse and recycling of materials, green public procurement, clean transport strategies, remanufacturing, etc. The priority has mainly been to reduce emissions (pollutants, noise, vibration) from all types of vehicles, develop policies on sustainable transport systems, and decouple transport from GDP growth. A wider approach to optimising the life-cycle of the transport systems is still lacking, and in particular the life-cycle of the infrastructure elements of those systems.

In addition, adaptation measures to increase the resilience of infrastructure have become vital for some EU regions which are more exposed to climate change and other threats. Current policy responses are focusing on gathering more technical and scientific knowledge, reviewing building and construction standards, finding sustainable, multi-functional and flexible urban and regional planning solutions and developing renewable energy sources to increase energy self-sufficiency.

Making infrastructures more resilient to climate change focuses on improving the capacity of the transport infrastructure network to withstand disruption, absorb disturbance and adapt to changing conditions under extreme circumstances. It refers to planning, materials, construction, management, etc. The resilience of transport infrastructure is a requirement not

only to adapt to climate change but also to ensure infrastructure maintenance and asset management.

This thematic area includes the following topics and actions:

TOPIC	**Effective decarbonisation over the whole life-cycle**		
Why is this a priority?	The measurement of carbon expended in the construction, maintenance, and deconstruction or recycling of infrastructure is underdeveloped. It is necessary to build, design and operate infrastructure aimed at minimising carbon emissions over its life-cycle. While whole life-cycle costs are commonly considered for financial purposes, it is unusual to do so for carbon.		
Actions	G.1.	Analyse the contribution of transport infrastructure to a resilient energy union and a forward-looking climate change and climate adaptation policy.	P
	G.2.	Develop a better understanding of carbon trade-offs between investing carbon in excess infrastructure capacity and the carbon used by traffic movements delayed by congestion or disruptions.	P
	G.3.	Develop the required standards for implementing trade-offs with CO_2 emissions for the whole life-cycle (taking into consideration the planning, design, construction, operation and decommissioning of infrastructures).	P
	G.4.	Develop design criteria for infrastructure aimed at minimising carbon emissions over the infrastructure's life-cycle, taking into consideration the carbon intensity of operating, maintaining and decommissioning infrastructure and the sustainability labelling of transport infrastructures, in line with the objectives of energy union.	P/T
	G.5.	Analyse how emissions derived from the maintenance of road pavements can be reduced and promote such a reduction.	P/T
	G.6.	Develop effective approaches to reduce the number and duration of construction sites of infrastructure to improve traffic movements; analyse the impact of emissions derived from works during the infrastructure's lifetime.	P/T
	G.7.	Analyse the positive impact and further development of materials which absorb pollutants in infrastructure construction and management (e.g. concrete, cooling pavements, etc.)	P/M

TOPIC	**Energy efficiency**		
Why is this a priority?	Facilitating a progressive reduction of the energy consumption of transport infrastructure in the whole life-cycle is essential for transport of the future, from a systemic and intermodal perspective.		
Actions	G.8.	Facilitate a progressive reduction of the energy consumption of transport infrastructure during its whole life-cycle.	P
	G.9.	Roll out vehicle recharging systems through the infrastructure.	T

TOPIC	**Adapting infrastructure to new energy resources**		
Why is this priority?	There is great potential to reduce both embedded and operational carbon in transport infrastructure and management, but this will require changes in the energy mix, changes in how people use the various modes, and changes in how users pay the direct and external or environmental costs of their travel.		
Actions	G.10.	Roll out infrastructure for alternative fuels, including the deployment of rapid electric charging infrastructure and storage of alternative fuels linked to renewable energy sources.	P
	G.11.	Perform an impact assessment of innovative mobility based on the use of new energy supply methods from the social, economic, and environmental perspective.	P
	G.12.	Analyse the potential of multimodal hubs as energy producers, storage and multimodal suppliers and their integration with the energy grid.	T

TOPIC	**Energy harvesting and storage**		
Why is this a priority?	After a long period of considering infrastructures as energy consumers, there are new trends of considering the potential capability of infrastructures to produce and store energy.		
Actions	G.13.	Create technologies for harvesting and recovering sustainable energy for future sustainable urban transport infrastructure	T

TOPIC	**Optimal operation of each mode**		
Why is this a priority?	The first aspect of transport operations aimed to reduce the transport's impact on the environment is to operate each mode or system as efficiently as possible, using operational measures to increase capacity or throughput.		
Actions	G.14.	Foster synergies and interconnection between energy and infrastructure systems.	M

TOPIC	**Preserving biodiversity and the landscape**		
Why is this a priority?	Although transport infrastructure has an unavoidable impact on the environment and wildlife, there are strategies and policies already in use to reduce it and integrate, to the extent possible, transport infrastructure without significantly affecting biodiversity. The value of the landscape should not be diminished by the impact of transport infrastructure, which should be properly integrated.		
Actions	G.15.	Standardise procedures for preserving and restoring the landscape, taking into consideration the inhabitants' and users' perspective as well as ecosystem services. Promote best practices for preserving the ecosystem along transport infrastructures.	P/M
	G.16.	Analyse and promote the role of infrastructures as a connector of fragmented habitats: from barriers to corridors.	M

TOPIC	**Air quality, noise and vibration**		
Why is this a priority?	With several political initiatives already in place, air quality legislation is mainly focused on the urban context. For noise and vibration, there are extensive initiatives to protect citizens from this negative impact of transport. Improving mobility should go hand in hand with reducing pollution in the EU.		
Actions	G.17.	Develop materials and methods to control and reduce the impact of usually non-controlled pollutants (such as tyre particles, de-icing substances and herbicides), as well as absorbent surface materials and those supporting the promotion of silent infrastructure.	M/T
	G.18.	Create advanced technologies and materials to lower pollution through smart infrastructure.	T

TOPIC	**Vulnerability under natural and man-made hazards**		
Why is this a priority?	The first step in implementing measures to adapt transport infrastructures to climate change is to identify the transport system's level of vulnerability, highlighting the need for rapid detection of disruptions and for cooperation among stakeholders.		
Actions	G.19.	Promote resilience by designing at a network level, including proven and effective measures to detect, prevent and mitigate man-made extreme events.	P/M
	G.20.	Implement a life-line approach in transport infrastructure for emergency management (to be understood as a corridor where assistance can be provided to potential victims and basic needs fulfilled), and consequently define and upgrade corridors.	M
	G.21.	Develop and implement tools, technologies and processes to support operations under all weather conditions and that they can be used to recover from congestion or disruptions in the transport network.	M
	G.22.	Implement methodologies and tools to measure the resilience of transport infrastructure by: ● implementing a multi-scale approach to assess the performance of transport infrastructure against different risks (climate change, terrorist attacks, etc.), taking into accounting as well cascading and interacting hazards (multi-hazard approach); and ● implementing algorithms to better detect critical points of the transport network.	T

TOPIC	Climate safeguard of infrastructures		
Why is this a priority?	Implementing a systemic approach for the planning, design, construction, operation, management and decommissioning of transport infrastructures that takes into account the effects of climate change essential for overcoming the impact of future changes.		
Actions	G.23.	Promote a climate-resilient infrastructure network, with procedures for identifying vulnerable areas and understanding the impacts of severe weather events and other events on infrastructure network (earthquakes, floods, landslides, droughts, storms, volcanoes…).	P
	G.24.	Adapt infrastructure to climate change by increasing the resilience against natural hazards, taking into consideration service performance and related costs balance. Define climate adaptation measures to develop cross-modal infrastructure and manage implementation strategies.	M
	G.25.	Use real-time information to forecast environmental hazards and expected impacts based on simulation/modelling.	T
	G.26.	Analyse the impact of infrastructure vulnerabilities (e.g. changes in prevailing wind direction in airports, potential noise impacts of changes in prevailing wind or increased temperature).	T

5.8. THEMATIC AREA H: LOGISTICS.

To ensure that transport chains are satisfying the needs of users, there have to be efficient logistics services. Logistics is a fundamental part of supply chain management. It consists of organising and managing flows of goods, which includes the purchase, production, warehousing, distribution, disposal, reuse and exchange of products, as well as the provision of added-value services. Today, companies often outsource their logistics activities to third-party logistics providers, and it is estimated that long-term contractual relationships, contract logistics, constitute 16% of total global logistics, while express/courier/parcel services are key to the e-commerce delivery business.
Co-modality (i.e. the efficient use of different transport modes on their own and in combination) and syncromodality (i.e. the selection of the best means of transport in any given time) will penetrate further in logistics, so that shippers will increasingly book transport and logistics service providers, under the supervision of a supply chain manager or integrator, which can contribute to a synchromodal solution. Blockchain technology is expected to change the structure of commerce and will therefore also affect and innovate logistics and supply chains, in particular for real-time planning of inventories, passenger flows, equipment and routing.

This thematic area includes the following topics and actions:

TOPIC	Innovations in logistics		
Why is this a priority?	To improve the framework for transport logistics operations, the European Union has identified a list of obstacles, which are mainly: a high administrative burden, inefficient transport chains, a lack of transport infrastructure and non-completion of the internal transport market.		
Actions	H.1.	Promote the role of infrastructure in door-to-door mobility for the entire logistics chain.	M
	H.2.	Promote infrastructure development, taking into account trends in logistics: focus on new infrastructure that allows fast transhipment of standardised load units.	T
	H.3.	Analyse the potential impact of innovation technologies on transport infrastructure.	T
	H.4.	Develop automated marshalling yards and intermodal terminals to connect with the rail mode.	T

TOPIC	Last mile solutions		
Why is this a priority?	Frequently in urban areas, last mile solutions in logistics have a high impact on emissions, safety, noise, air quality, etc. There is a clear connection between improving last mile solutions and improving people's quality of life.		
Actions	H.5	Conduct research on the transport infrastructure needed for new, sustainable and smart ways of delivering goods to make better use of urban space (e.g. by means of robots and air drones).	M

5.9. ADDITIONAL ACTIONS.

The following actions are complementary and serve as a framework for developing R&I in transport infrastructure:

Mobility as a service:

- Achieve optimal travel experience based on the coordination of infrastructure owners and service providers.
- Incorporate users' expectations as a quality factor for the service provided by different types of transport infrastructures, including their multi-use character.
- Adapt infrastructure to demographic change and personal mobility needs, paying special attention to vulnerable users.
- Create friendly environments for inclusive mobility and accessibility for persons of different ages, social categories, impairment, etc.
- Promote soft modes, such as walking and cycling, ensuring safety and quality of service from infrastructure.

Capacity and reducing congestion:

- Introduce a commitment to on-time delivery (freight and passengers)
- Analyse the feasibility of sharing the use of physical infrastructure (e.g. off-peak use of underground or light-rail passenger networks or inland navigation to distribute goods, mixed and flexible use of urban waterfront, parking sharing).

Quality of service:

- Analyse how infrastructure helps to improve the user's transport experience, knowing that infrastructure is a major contributor to the experience.
- Create / adapt the infrastructure to facilitate the last mile solutions, especially in urban environments and for delivery services.
- Do an assessment of the contribution of transport modes and services (e.g. personal air vehicles, innovative air vehicles, innovative concepts for complementing urban and inter-regional travel) to the 4-hour door-to-door mobility goals for air transport.
- Analyse different transport modes and users' quality needs in relation to infrastructure.

Cooperation among different stakeholders:

- Analyse the impact of EU-financing and cooperation instruments (Connecting Europe Facility, European Structural and Investment Funds, Trans-European Transport Network policy implementation, framework programmes for R&I, etc.) on cohesion, economic and social life, wealth, etc.
- Maintain and promote collaboration between public and private stakeholders in transport in order to ensure that the steps taken by the service providers and industry are in accordance with transport infrastructure advances, while keeping safety and security as the backbone of the service.
- Explore innovative operation models based on the sharing of infrastructure between different stakeholders: publicly owned and operated systems can work in tandem with privately owned and run services.
- Create mechanisms of support for cities and local communities in a new transport infrastructure vision.
- Exploit synergies between different electricity, heating and cooling networks, fuel networks, transport infrastructure and telecom networks (key for enabling the smart, integrated and flexible operation of the relevant infrastructures).

Communication and participation strategies:

- Improve participation processes, and develop new ones, to gain social acceptance for policy options (and participate in their design) on innovative strategies (for example, for decarbonisation), going beyond the traditional public consultation.
- Create consultation platforms with multiple stakeholders to overcome gaps in the legal framework and regulations in order to ensure the optimal performance of transport infrastructure.

Incentives for research:

- Explore new mechanisms of financial support for research programmes, including, for example, donations or crowdfunding, as well as cooperation with non-EU countries.
- Continuously update innovative fields of work in research programmes (e.g. energy harvesting, implications of proper maintenance of infrastructure on safety, climate resilience, energy consumption and carbon production, etc.).

New skills and competencies of workforce:

- Develop skills linking infrastructures and mobility innovations.
- Promote ways to attract skilled professionals (for example, from the information and communications technologies sector) to infrastructure in order to satisfy future needs for mobility, ensuring lifelong learning and training.
- Link education and research in transport infrastructure and promote the involvement of students in research projects, taking diversity into account, in order to prepare a resource pool of future experts.

6. STRATEGIC IMPLEMENTATION PLAN

This chapter includes the actions identified in the previous chapter and lists them according to the type of action (policy, management or technology). It also provides information on the time framework for the different actions proposed and indicates who is mainly responsible, i.e.:

- the European Commission (EC).
- the Member States (MS).
- the private sector (PS).

The academic world has not been specifically included as mainly responsible, as they are key partners for almost every action proposed. Key performance indicators are proposed at the end of the chapter.

6.1. POLICY ACTIONS AND STRATEGIC MANAGEMENT ACTIONS.

The following tables include information on policy actions and management actions.

AREA	TOPIC	POLICY ACTIONS		SHORT TERM (2020-2025)	MEDIUM TERM (2025-2030)	LONG TERM (2030 - 2040)
GOVERNANCE	Planning	A.1.	Plan infrastructures according to national, European and world mobility needs, with a cross-modal perspective from an early stage, and taking into consideration infrastructure as a generator of regional and national development and cohesion.	EC MS		
		A.2.	Develop infrastructure for public transport systems and soft modes, such as walking or cycling, to make mobility systems more attractive and environmentally friendly (e.g. reserved lanes).	EC MS		
		A.4.	Analyse the relationship between spatial planning and transport infrastructure, as a base for optimised mobility solutions.	MS		
	Legal framework and regulations	A.6.	Identify regulatory incentives and barriers which are relevant for a more efficient construction, upgrade and use of infrastructure, avoiding isolated solutions.	MS		
	Procurement	A.7.	Ensure the implementation of a legal framework for incentives and penalties in procurement processes. Promote innovative and optimal solutions and reinforce the integrity and transparency of the process, ensuring best value for money from a societal perspective.		EC MS	
		A.8.	Foster green public procurement (particularly focused on the reduction of emissions, recycling and climate adaptation and mitigation) and innovative public procurement of transport infrastructure.	MS		
		A.9.	Implement contractual performance indicators to improve the operation of transport.	MS	a	
		A.10.	Strengthen capabilities for preparing and conducting public procurement of transport infrastructures. Foster the early participation of all relevant stakeholders in the preparation and procurement of EU funded large-scale infrastructures.	EC MS		
	Standardisation	A.11.	Improve and create standards for transport infrastructures and data aggregation in a new mobility framework.		EC MS PS	
LIFE-CYCLE AND ASSET MANAGEMENT	Reutilisation and recycling – circular economy	B.3.	Develop policy guidelines to promote circular economy for transport infrastructure during its whole life-cycle, including decommissioning, highlighting the reuse of materials.	EC MS		
		B.4.	Analyse the improved emission efficiency of infrastructure reuse and the potential for greater cost efficiency.	EC MS		
	Maintenance and	B.5.	Introduce new contractual performance indicators, regulatory and public procurement	MS		

	regeneration as a strategic policy		models and incentives to maintain and upgrade infrastructure.			
		B.6.	Promote synergies so that maintenance operations in transport infrastructure go hand in hand with greater resilience of the infrastructure.		MS	
	Project delivery / implementation phase	B.8.	Implement project control and risk management tools and technologies, including artificial intelligence, big data, etc. that enhance accountability and support the achievement of the project objectives.		PS	
	Asset management	B.10.	Increase the ability of infrastructure to adapt faster to new developments (e.g. innovative transport means and technologies) and rapid changes in demand.	MS		
		B.11.	Implement a wide vision for asset management at national level (corridor and network management instead of particular elements) and across borders.	EC MS		
FINANCING, PRICING AND TAXATION	Value for money	C.1.	Implement a standardised methodology for a cost-benefit analysis including decarbonisation objectives, as well as other externalities, for all transport infrastructure projects, during the whole life-cycle.	EC MS		
		C.2.	Analyse diversified infrastructure funds with earmarked and multiple sources of financing (budgets, fuel taxes, user charges, savings) and some cross financing from taxes and revenues.	EC MS		
	Public-private partnership	C.5.	Explore innovative financing methods in a more efficient way; this would include the potential participation of new stakeholders, crowdfunding.		EC MS	
	Pricing and charging strategies	C.6.	Analyse the potential of a fair and efficient pricing of transport infrastructure, including emission taxation and better internalisation of external costs, across modes, in order to create a level playing field.	EC MS		
	Public awareness	C.7.	Implement strategies for greater public awareness and acceptability towards infrastructure pricing.	MS		
TECHNOLOGY AND DIGITALISATION	Smart infrastructure	D.1.	Adapt infrastructure to support developments in technology so that new business models enabling smart infrastructure can be rapidly deployed.	EC MS PS		
		D.2.	Provide full interoperability across the modal chain, allowing passengers and freight to switch seamlessly between modes and across borders.		EC MS PS	
	Connected infrastructure	D.3.	Set up infrastructure to collect and manage information and data that can be used to monitor the performance of the infrastructure (asset utilisation rate).	MS PS		
MULTIMODALITY, INTEROPER	Integrated operation across modes	E.1.	Develop a strategy for EU transport integration, syncromodality, intermodality and interoperability, ensuring the infrastructure enables seamless interchange of freight and passengers.	EC MS		

ABILITY AND INTERCONNECTIVITY.	Integration of multimodal nodes	E.5.	Include transport infrastructure optimisation in sustainable urban mobility plans, for all modes and multi-functional environments.	MS		
SAFETY AND SECURITY	Reduction of risks by integrating safety as a priority in the whole life-cycle of transport infrastructures.	F.1.	Maintain high EU safety and security standards, by implementing and following up on risk and performance indicators for all transport infrastructures, including across borders.	EC MS		
		F.2.	Develop smart tools for predictive assessment and real-time monitoring of safety risks and system effectiveness of infrastructure.		PS	
		F.3.	Utilise cost-effectiveness analysis when analysing to what extent a given infrastructural solution and technologies can potentially improve safety.		MS	
		F.4.	Implement approaches that aim at zero accidents for all transport modes, taking into consideration all the stakeholders and including the concept of 'forgiving infrastructure', which compensates for human errors and therefore reduces the risk and consequences of accidents.	MS PS		
	Safety of vulnerable users	F.12.	Develop dedicated infrastructure for vulnerable users (e.g. pedestrians and cyclists or users of small boats, but also including users of new forms of mobility such as e-scooters).	MS		
	Protection of infrastructures against attacks.	F.15.	Promote a cross-modal security strategy that protects infrastructure from trespass/security/terrorist threats by using devices and systems that automatically detect security breaches.	MS PS		
SUSTAINABILITY, ENVIRONMENT AND RESILIENCE	Effective decarbonisation over the whole life-cycle	G.1.	Analyse the contribution of transport infrastructure to a resilient energy union and a forward-looking climate change and climate adaptation policy.	EC MS		
		G.2.	Develop a better understanding of carbon trade-offs between investing carbon in excess infrastructure capacity and the carbon used by traffic movements delayed by congestion or disruptions.		MS	
		G.3.	Develop the required standards for implementing trade-offs with CO_2 emissions for the whole life-cycle (taking into consideration the planning, design, construction, operation and decommissioning of infrastructures).		EC	
		G.4.	Develop design criteria for infrastructure aimed at minimising carbon emissions over the infrastructure's life-cycle, taking into consideration the carbon intensity of operating, maintaining and decommissioning infrastructure and the sustainability labelling of transport infrastructures, in line with the objectives of energy union.	EC MS		
		G.5.	Analyse how emissions derived from the maintenance of road pavements can be reduced and promote such a reduction	MS		
		G.6.	Develop effective approaches to reduce the number and duration of construction sites of infrastructure to improve traffic movements; analyse the impact of emissions derived from		MS	

			works during the infrastructure's lifetime.			
		G.7.	Analyse the positive impact and further development of materials which absorb pollutants in infrastructure construction and management (e.g. concrete, cooling pavements, etc.)	MS PS		
	Energy efficiency	G.8.	Facilitate a progressive reduction of the energy consumption of transport infrastructure during its whole life-cycle.	PS		
	Adaptation of infrastructure to new energy resources	G.10.	Roll out infrastructure for alternative fuels, including the deployment of rapid electric charging infrastructure and storage of alternative fuels linked to renewable energy sources.	MS		
		G.11.	Perform an impact assessment of innovative mobility based on the use of new energy supply methods from the social, economic, and environmental perspective.		EC MS	
	Preservation of biodiversity and landscape	G.15.	Standardise procedures for preserving and restoring the landscape, taking into consideration the inhabitants' and users' perspective as well as ecosystem services. Promote best practices for preserving the ecosystem along transport infrastructures.		EC MS	
	Vulnerability under natural and man-made hazards	G.19.	Promote resilience by designing at a network level, including proven and effective measures to detect, prevent and mitigate man-made extreme events.	MS PS		
	Climate safeguard of infrastructures	G.23.	Promote a climate-resilient infrastructure network, with procedures for identifying vulnerable areas and understanding the impacts of severe weather events and other events on infrastructure network (earthquakes, floods, landslides, droughts, storms, volcanoes…).	MS		

AREA	TOPIC	MANAGEMENT ACTIONS		SHORT TERM (2020-2025)	MEDIUM TERM (2025-2030)	LONG TERM (2030 - 2040)
GOVERNANCE	Planning	A.3.	Optimise methods to better take into consideration users' expectations and travel trends in planning procedures. These methods might be based on the use of big data, artificial intelligence and other technologies.		MS PS	
		A.4.	Analyse the relationship between spatial planning and transport infrastructure, as a base for optimised mobility solutions.	MS		
	Legal framework and regulations	A.6.	Identify regulatory incentives and barriers which are relevant for a more efficient construction, upgrade and use of infrastructure, avoiding isolated solutions.	MS		
LIFE-CYCLE AND ASSET MANAGEMENT	Use of new construction processes and materials	B.1.	Use more sustainable materials and promote advanced features, such as self-healing materials.	MS PS		
		B.2.	Promote advanced and novel construction methods that include modularisations and smart concepts, facilitate automated solutions, and ensure adaptation to the new demands with low-intrusive, fast and cost-efficient infrastructure. Optimise production techniques for the prefabrication of infrastructure elements.	EC MS PS		
	Maintenance and regeneration as a strategic policy	B.6.	Promote synergies so that maintenance operations in transport infrastructure go hand in hand with greater resilience of the infrastructure.		MS	
	Project delivery / implementation phase	B.8.	Implement project control and risk management tools and technologies, including artificial intelligence, big data, etc. that enhance accountability and support the achievement of the project objectives.		PS	
		B.9.	Promote a platform for closer cooperation and exchange of information and data between the project owners, infrastructure operator, funding bodies, etc.		MS PS	
	Asset management	B.12.	Use existing capacity more efficiently by maximising the utilisation of assets for transport infrastructure and systems.	MS		
		B.13.	Conduct a predictive analysis of capacity crunch within each transport mode, taking	MS		

			into account multimodal transport.	PS		
		B.14.	Integrate and upgrade information systems and remote sensing to ensure the proper decision-making process on prioritisation of asset operations and maintenance.		MS PS	
FINANCING, PRICING AND TAXATION	Value for **m**oney	C.3.	Increase the amount and quality of data used for cost-benefit analysis during the life-cycle of infrastructures, using different technologies and benchmarking techniques.	MS PS		
		C.4.	Model the impact of the level of investment in transport infrastructure from a holistic perspective (considering all economic, social, environmental and other factors).	EC MS		
	Pricing and charging strategies	C.6.	Analyse the potential of a fair and efficient pricing of transport infrastructure, including emission taxation and better internalisation of external costs, across modes, in order to create a level playing field.	EC MS		
TECHNOLOGY AND DIGITALIZATION	Connected infrastructure	D.4.	Create added-value services based on the data collected from physical and digital infrastructure.		MS PS	
		D.5.	Develop, in a connected environment, of logistics hubs, parking lots and networks for future freight operations.	PS		
MULTIMODALITY, INTEROPERABILITY AND INTERCONNECTIVITY	Integrated operation across modes	E.2.	Conduct an analysis of the main weaknesses and bottlenecks preventing a genuine integration, interoperability and intermodality of different modes of transport, from the customer perspective, including the optimal location and accessibility.	MS PS		
SAFETY AND SECURITY	Reduction of risks by integrating safety as a priority in the whole life-cycle of transport infrastructures	F.4.	Implement approaches that aim at zero accidents for all transport modes, taking into consideration all the stakeholders and including the concept of 'forgiving infrastructure', which compensates for human errors and therefore reduces the risk and consequences of accidents.	MS PS		
		F.5.	Develop tools for evaluating the potential effectiveness of information and communication technologies in improving safety.		MS PS	
		F.11.	Improve safety for workers and users in work zones.	MS		
	Safety of vulnerable users	F.13.	Analyse solutions to improve the safety of the elderly and disabled.	MS		
		F.14.	Assess users' vulnerability in terms of their lack of access to data and communication opportunities, in order to foster an inclusive, digitally interconnected transport system.		MS PS	
	Protection of infrastructures against attacks	F.16.	Identify critical infrastructures and critical points/sections, including across borders.	MS PS		
		F.17.	Maintain the right level of cybersecurity throughout the overall life of the	MS		

			infrastructure.	PS		
SUSTAINABILITY, ENVIRONMENT AND RESILIENCE	Effective decarbonisation over the whole life-cycle	G.7.	Analyse the positive impact and further development of materials which absorb pollutants in infrastructure construction and management (e.g. concrete, cooling pavements, etc.)	MS		
	Optimal operation of each mode	G.14.	Foster synergies and interconnection between energy and infrastructure systems.		MS	
	Preservation of biodiversity and landscape	G.15.	Standardise procedures for preserving and restoring the landscape, taking into consideration the inhabitants' and users' perspective as well as ecosystem services. Promote best practices for preserving the ecosystem along transport infrastructures.		MS	
		G.16.	Analyse and promote the role of infrastructures as a connector of fragmented habitats: from barriers to corridors.	MS		
	Air quality, noise and vibration	G.17.	Develop materials and methods to control and reduce the impact of usually non-controlled pollutants (such as tyre particles, de-icing substances and herbicides), as well as absorbent surface materials and those supporting the promotion of silent infrastructure.	MS		
	Vulnerability under natural and man-made hazards	G.19.	Promote resilience by designing at a network level, including proven and effective measures to detect, prevent and mitigate man-made extreme events.	MS		
		G.20.	Implement a life-line approach in transport infrastructure for emergency management (to be understood as a corridor where assistance can be provided to potential victims and basic needs fulfilled), and consequently define and upgrade corridors.	MS		
		G.21.	Develop and implement tools, technologies and processes to support operations under all weather conditions and that they can be used to recover from congestion or disruptions in the transport network.		MS	
	Climate safeguard of infrastructures	G.24.	Adapt infrastructure to climate change by increasing the resilience against natural hazards, taking into consideration service performance and related costs balance. Define climate adaptation measures to develop cross-modal infrastructure and manage implementation strategies.	MS		
LOGISTICS	Innovations in logistics	H.1.	Promote the role of infrastructure in door-to-door mobility for the entire logistics chain.	MS		
	Last mile	H.5.	Conduct research on the transport infrastructure needed for new sustainable and		MS	

	solutions		smart ways of delivering goods to make better use of urban space (e.g. by means of robots and air drones).			

6.2. ACTIONS WITH A SIGNIFICANT TECHNOLOGICAL COMPONENT.

The following table includes information on technology actions.

AREA	TOPIC	TECHNOLOGY ACTIONS		SHORT TERM (2020-2025)	MEDIUM TERM (2025-2030)	LONG TERM (2030 - 2040)
GOVERNANCE	Planning	A.2.	Develop infrastructure for public transport systems and soft modes, such as walking or cycling, to make mobility systems more attractive and environmentally friendly (e.g. reserved lanes).	EC MS		
		A.3.	Optimise methods to better take into consideration users' expectations and travel trends in planning procedures. These methods might be based on the use of big data, artificial intelligence and other technologies.		MS PS	
		A.5.	Develop and use simulation, planning tools, assessment methods and consultations to support project prioritisation and evidence-based decision-making during the infrastructure life-cycle.		MS PS	
LIFE-CYCLE AND ASSET MANAGEMENT	Use of new construction processes and materials	B.2.	Promote advanced and novel construction methods that include modularisations and smart concepts, facilitate automated solutions, and ensure adaptation to the new demands with low-intrusive, fast and cost-efficient infrastructure. Optimise production techniques for the prefabrication of infrastructure elements.	EC MS PS		
	Maintenance and regeneration as a strategic policy	B.7.	Develop new methods for the maintenance and upgrade (predictive and preventive) of transport infrastructure in order to improve safety, availability, climate resilience and environmental impact, achieve cost optimisation, and develop new solutions to accommodate connected mobility.	PS		
	Project delivery / implementation phase	B.9.	Promote a platform for closer cooperation and exchange of information and data between the project owners, infrastructure operator, funding bodies, etc.		MS PS	
	Asset management	B.14.	Integrate and upgrade information systems and remote sensing to ensure the proper decision-making process on prioritisation of asset operations and maintenance.		MS PS	
		B.15.	Develop the asset management of multi-use infrastructure in order to improve the safety and capacity/performance of transport infrastructure and ensure better maintenance while at the same time improving sustainability and climate resilience.		MS	

FINANCING, PRICING AND TAXATION	Value for **m**oney	C.3.	Increase the amount and quality of data used for cost-benefit analysis during the life-cycle of infrastructures, using different technologies and benchmarking techniques.	MS PS		
	Public awareness	C.8.	Use big data and activity-based models to better understand users' reactions in order to fine tune infrastructure pricing strategies.	MS PS		
TECHNOLOGY AND DIGITALISATION	Smart infrastructure	D.1.	Adapt infrastructure to support developments in technology so that new business models enabling smart infrastructure can be rapidly deployed.	EC MS PS		
		D.2.	Provide full interoperability across the modal chain, allowing passengers and freight to switch seamlessly between modes and across borders.		EC MS PS	
	Connected infrastructure	D.3.	Set up infrastructure to collect and manage information and data that can be used to monitor the performance of the infrastructure (asset utilisation rate).	MS PS		
		D.4.	Create added-value services based on the data collected from physical and digital infrastructure.		MS PS	
		D.6.	Identify infrastructure and equipment requirements for deploying technologies (sensors, software, systems, high performance computing, artificial intelligence, etc.) destined for autonomous multimodal transport.	MS PS		
		D.7.	Develop methods to balance the impact of new and existing technologies on the transport system and on the required infrastructure capacity.	MS		
	Digitalisation, artificial intelligence and big data	D.8.	Introduce strategies for the automated construction and maintenance of infrastructure.			
		D.9.	Use artificial intelligence (including data collection and exchange protocols and standards) to better plan and deliver transport infrastructures and manage assets.			
	Automation/ robotisation /remote solutions	D.10.	Foster smart infrastructures and condition-based maintenance (sensing and inspection combined with models for degradation and structural integrity), including the development of self-monitoring and self-healing infrastructures.		PS	
		D.11.	Use robotised equipment and innovative technologies (such as artificial intelligence, radar, ultrasound, inspection robots, satellite systems, etc.) to perform routine periodic maintenance, survey, inspection and monitoring or emergency works, reducing the risks and costs, while increasing the availability of infrastructure.			PS
MULTIMODALITY, INTEROPERABILITY AND	Integrated operation across modes	E.3.	Perform an analysis of the requirements of multimodal hubs, in terms of infrastructures and services, for smart and seamless intermodality.		MS PS	

INTERCONNECTIVITY	Integration of information	E.4.	Develop demonstrations and implement on a small-scale in order to show technologies and new forms of information-sharing needed to improve the integration of transport systems, address challenges for intermodal nodes, etc.	MS PS		
	Integration of multimodal nodes	E.6.	Perform modelling of inland waterways / port-city opportunities and integrate water freight & passenger solutions into new forms of mobility.	MS		
SAFETY AND SECURITY	Reduction of risks by integrating safety as a priority in the whole life-cycle of transport infrastructures	F.6.	Anticipate and provide solutions to emerging risks in the transition phases (e.g. highly automated vessels or vehicles in mixed road traffic) and in the shared infrastructures (e.g. mix of cars, scooters, and bikes in roads; inland and maritime shipping for passengers and freight).			MS PS
		F.7.	Implement models of the system/sub-systems behaviour that are able to automatically assess how an asset failure affects the infrastructure systems.		MS PS	
		F.8.	Improve the management of critical interfaces between operators, modes or different countries, using advanced solutions and analysis.		MS	
		F.9.	Analyse concepts and procedures for introducing safety-relevant tools and methods based on artificial intelligence.		PS	
		F.10.	Ensure safe interaction of users with vehicles and infrastructure in the digital environment (human-machine and human-infrastructure interface).	PS		
		F.11.	Improve safety for workers and users in work zones.	MS		
	Protection of infrastructures against attacks	F.17.	Maintain the right level of cybersecurity throughout the overall life of the infrastructure.	MS PS		
		F.18.	Ensure the development of maintainable innovative security solutions based on the use of technologies and security risk management.		MS PS	
SUSTAINABILITY, ENVIRONMENT AND RESILIENCE	Effective decarbonisation over the whole life-cycle	G.4.	Develop design criteria for infrastructure aimed at minimising carbon emissions over the infrastructure's life-cycle, taking into consideration the carbon intensity of operating, maintaining and decommissioning infrastructure and the sustainability labelling of transport infrastructures, in line with the objectives of energy union.	EC MS		
		G.5.	Analyse how emissions derived from the maintenance of road pavements can be reduced and promote such a reduction	MS PS		
		G.6.	Develop effective approaches to reduce the number and duration of construction sites of infrastructure to improve traffic movements; analyse the impact of emissions derived from works during the infrastructure's lifetime.		MS	
	Energy	G.9.	Roll out vehicle recharging systems through the infrastructure.		MS	

	efficiency					
	Adaptation of infrastructure to new energy resources	G.12.	Analyse the potential of multimodal hubs as energy producers, storage and multimodal suppliers and their integration with the energy grid.			MS PS
	Energy harvesting and storage	G.13.	Create technologies for harvesting and recovering sustainable energy for future sustainable urban transport infrastructure		PS	
	Air quality, noise and vibration	G.17.	Develop materials and methods to control and reduce the impact of usually non-controlled pollutants (such as tyre particles, de-icing substances and herbicides), as well as absorbent surface materials and those supporting the promotion of silent infrastructure.	PS		
		G.18.	Create advanced technologies and materials to lower pollution through smart infrastructure.	PS		
	Vulnerability under natural and man-made hazards	G.22	Implement methodologies and tools to measure the resilience of transport infrastructure by: ● implementing a multi-scale approach to assess the performance of transport infrastructure against different risks (climate change, terrorist attacks, etc.), taking into accounting as well cascading and interacting hazards (multi-hazard approach); and ● implementing algorithms to better detect critical points of the transport network.		MS PS	
	Climate safeguard of infrastructures	G.25.	Use real-time information to forecast environmental hazards and expected impacts based on simulation/modelling.		PS	
		G.26.	Analyse the impact of infrastructure vulnerabilities (e.g. changes in prevailing wind direction in airports, potential noise impacts of changes in prevailing wind or increased temperature).		MS PS	
LOGISTICS	Innovations in logistics	H.2.	Promote infrastructure development, taking into account trends in logistics: focus on new infrastructure that allows fast transhipment of standardised load units.		PS	
		H.3.	Analyse the potential impact of innovation technologies on transport infrastructure.		PS	
		H.4.	Develop automated marshalling yards and intermodal terminals to connect with the rail mode.	PS		

6.3. KEY PERFORMANCE INDICATORS.

The following key performance indicators are proposed for the follow-up of the actions included in this STRIA roadmap on transport infrastructure:

Thematic area 'Governance':

- Percentage of investment in transport infrastructure projects developed with green public procurement and innovative public procurement.
- Total length of dedicated infrastructures for public transport and associated investment.

Thematic area 'Life-cycle and asset management':

- Percentage of investment in maintenance over the total value of the transport infrastructure.
- Number of units (e.g. tonnes) of reused and recycled material utilised for transport infrastructure construction and upgrading.
- Savings in carbon emissions by utilising reused and recycled material.
- Savings in energy consumption by utilising reused and recycled material.
- Number of hours of congestion on transport infrastructure networks.
- Savings in carbon emissions by reducing congestion reduction.
- Savings in energy consumption by reducing congestion.
- Saving in energy consumption derived from congestion reduction.
- Number of R&I projects in this field, their budget and the number of organisations having participated in them.

Thematic area 'Financing, pricing and taxation':

- Percentage of infrastructure projects built and managed on the basis of a systemic cost-benefit analysis.
- Social acceptance to charging policies (surveys).
- Percentage of kilometres of transport infrastructures or areas under charging schemes.

Thematic area 'Technology and digitalisation':

- Total kilometres (or other units) of transport infrastructures built and managed with smart criteria in terms of connectivity and services provided.
- Connected mobile devices used for mobility purposes.
- Total investment in technology in transport infrastructures.
- Number of R&I projects in this field, their budget and the number of organisations having participated in them.

Thematic area 'Multimodality, interoperability and interconnectivity':

- Percentage of total length of Trans European Network allowing intermodality and interoperability.

Thematic area 'Safety and security':

- Trends in safety – serious incidents; killed and seriously injured.
- Percentage of networks built and managed under EU safety standards in Member States.
- Total length of dedicated infrastructures for cyclists or pedestrians and associated investment.
- Percentage of networks under security risks assessment.

Thematic area 'Sustainability, environment and resilience':

- Percentage of yearly variation of total energy consumption of transport infrastructure.
- Percentage of energy consumed in transport which is own-generated by transport itself.
- Units of transport infrastructure which are equipped to fully allow electro-mobility and other alternatives.
- Number of incidents and events causing significant disruption.
- Consequences of disruptions in lives lost and monetary value.

Thematic area 'Logistics':

- Number of intermodal hubs integrated in infrastructure networks.
- Percentage of logistics centres with total interoperability with information technologies applications.

In addition, the following indicators are suggested for each thematic area and topic (van Balen et al. 2019):

- Number of R&I projects.
- Total budget of projects.
- Number of organisations involved.
- Presence of public owners of infrastructure in the consortiums.
- Technology readiness level (TRL) of project results.

7. CONCLUSIONS

The EU aims to build a modern, integrated transport system that strengthens the EU's global competitiveness and meets the challenges of sustainable, smart and inclusive growth. The EU's physical infrastructure includes over 217 000 km of railways, 77 000 km of motorways, 42 000 km of inland waterways, 329 key seaports and 325 airports.

Infrastructure should ensure a well-functioning base to transport people and goods efficiently, safely and sustainably. Today, transport infrastructures are facing an increasing number of challenges related to the environment, safety, resilience, governance, financing, pricing, interoperability, life-cycle optimisation, digitalisation, etc. Infrastructures should adapt to overcome these challenges, while ensuring the required competitiveness of European industries, territorial cohesion, multimodality, the provision of services to inhabitants and visitors, etc
This roadmap shows and empowers the role of R&I in improving transport infrastructures to face the challenges mentioned, as a fundamental part of our modern and social-economic life. Most of the topics

and actions in this roadmap are related to other STRIA roadmaps, showing a high interdependence among them. Consequently, the seven roadmaps should be considered as a group.

The STRIA roadmap on transport infrastructure identifies the following thematic areas and topics as priorities for R&I, as shown in the table below. A total of 100 actions are described, covering policy, management and technology.

The European Commission, the Member States and the private sector have a leading role to play in each of the actions defined, while academia will be involved in most of the activities planned.

THEMATIC AREAS	TOPICS
A. Governance	Planning
	Legal framework and regulations
	Procurement
	Standardisation
B. Life-cycle and asset management	Using new construction processes and materials
	Reutilisation and recycling – circular economy
	Maintenance and regeneration as a strategic policy
	Project delivery / implementation phase
	Asset management
C. Financing, pricing and taxation	Value for money
	Public-private partnership
	Pricing and charging strategies
	Public awareness
D. Technology and digitalisation	Smart infrastructure
	Connected infrastructure
	Digitalisation, artificial intelligence and big data
	Automation/ robotisation / remote solutions
E. Multimodality, interoperability and interconnectivity	Integrated operation across modes
	Integration of information
	Integration of multimodal nodes
F. Safety and security	Reducing risks by integrating safety as a priority in the whole life-cycle of transport infrastructures.
	Safety of vulnerable users
	Protecting infrastructures against attacks.
G. Sustainability, environment and resilience	Effective decarbonisation over the whole life-cycle
	Energy efficiency
	Adapting infrastructure to new energy resources
	Energy harvesting and storage
	Optimal operation of each mode
	Preservation of biodiversity and landscape
	Air quality, noise and vibration
	Vulnerability under natural and man-made hazards
	Climate safeguard of infrastructures
H. Logistics	Innovations in logistics
	Last mile solutions

Most of the actions proposed have been identified as short term, given that the first steps should be taken between 2020 and 2025, but they will have to be monitored and updated in the years after that.

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ANNEX 1: DETAILED STATE OF THE ART

STRIA Roadmaps (2017)

In 2015 the strategy on energy union provided a framework to achieve EU energy and climate goals. Indeed, the Commission articulated the need to develop a forward-looking, energy and climate-related R&I strategy to maintain European technological leadership and expand export opportunities. It also proposed a European energy R&I approach, comprising an upgraded strategic energy technology plan and a strategic transport R&I agenda (STRIA), with a few essential priorities and clear objectives.

Designed in coordination with Member States and transport stakeholders, STRIA is composed of roadmaps whose aim is to ensure a more integrated and effective transport system across Europe, making better use of innovation and new technology in transport. The roadmaps integrate seven thematic areas of research on transport, of which transport infrastructure is one of them.

European technology platforms

European technology platforms (ETPs), which are industry-led stakeholder forums recognised by the European Commission, are key actors that develop R&I agendas, roadmaps for action at EU and national level to be supported by both private and public funding. ETPs mobilise stakeholders to deliver on agreed priorities and share information across the EU. They are sector-focused structures, but they also foster networking opportunities and international cooperation to address cross-sectoral challenges.

Many ETPs are relevant for transport infrastructure:

- ACARE, the Advisory Council for Aviation Research and Innovation in Europe;
- ALICE, Alliance for Logistics Innovation through Collaboration in Europe
- ECTP, the European Construction, built environment and energy efficient building Technology Platform to promote the future of the Built Environment;
- ERRAC, the European Rail Research Advisory Council;
- ERTRAC, the European Road Transport Research Advisory Council;
- WATERBORNE, the European research and innovation platform for waterborne industries.

ACARE – Strategic Research and Innovation Agenda 2017 update – Delivering Europe's Vision for Aviation

In 2011 a European group of experts set out a vision of European aviation with the publication of Flightpath 2050. Today Flightpath 2050's ambitious goals remain valid, seeking to deliver two aims: firstly to serve society's needs for safe, more efficient and environmentally friendly air transport; and secondly, to maintain global leadership for Europe in the aviation sector with a competitive supply chain and competitive operators.

In response to this, in 2012 ACARE produced a strategic research and innovation agenda (SRIA) that defined the path to reach these ambitious goals. An update was delivered in 2017, in particular addressing the following additional recommendations to airports to:

- develop capabilities to evaluate mobility concepts, infrastructure and performance;
- evolve airports into integrated, efficient and sustainable air transport interface nodes;
- improve the airport environment (especially by decreasing emissions).

ALICE - Corridors, hubs and syncromodality r&i roadmap (2018)

The European technology platform ALICE was set up to develop a comprehensive strategy for research, innovation and the market deployment of logistics and supply chain management innovation in Europe.

The ambition of this roadmap is to achieve EU-wide co-modal transport services within a well synchronised, smart and seamless network, supported by corridors and hubs, providing optimal support to supply chains.

In order to obtain a connected system, integration must be achieved between the horizontal layers. Two main areas of innovation were defined, with three underlying pathway topics for each area (all in relation to transport infrastructure):

A. Integration of transport services and supply chains
    1. Understanding the demand for the syncromodal freight transport system
    2. Optimising alignment between supply chains and transport services
    3. New roles for hubs in the supply chain
B. Integration of transport services and infrastructures
    4. An integrative freight network strategy
    5. Transport chain design and operation for syncromodality
    6. Deploying ICT as integrating technology.

ECTP FP9 Position Paper (June 2018)
The high-tech building industry in support of EU energy, climate and sustainability objectives. Towards a generalised European low-carbon & resilient built environment

The main mission of the ECTP (European Construction, built environment and energy-efficient building Technology Platform), along with one of its main instruments for energy efficiency, the EeB cPPP (Energy efficient Building contractual Public-Private Partnership), is to (i) develop and implement new research, development and innovation strategies (RDI) to improve the competitiveness of the EU construction industry, (ii) meet societal needs and (iii) take up environmental challenges through an innovative built environment.

A specific paper is dedicated to **infrastructure and mobility**.

This paper states that in order to make the implementation of new and sustainable transport systems real and feasible, infrastructure needs to be physically and technologically upgraded and adapted. For instance:

- Intelligent infrastructure, which enables data to be collected and analysed in real time, will provide increased operational efficiency for infrastructure as well as for mobility.
- Reduced operation and maintenance costs for the assets can be achieved by making better informed decisions.
- New, non-disruptive techniques for the upgrade and maintenance of infrastructure will help to achieve steady traffic flows.
- New materials (e.g. self-healing materials) can provide cost-effective strengthening capabilities to old infrastructures.
- Infrastructure needs to be resilient to the effects of climate change and man-made hazards.

Four priority areas for R&D and innovation were proposed in this paper: urban mobility, multimodal hubs, long-distance corridors, systemic approach.

ERRAC Rail 2050 Vision

ERRAC's Rail 2050 Vision, originally published in 2018, describes today's rail sector in terms of its contribution to the economy, society and the environment and looks at the challenges and opportunities arising from societal changes and other trends. It also presents a view of what Europe's railways might look like in 2050 if they take advantage of opportunities to innovate, and looks at the bigger contribution rail could make. The document identifies the key enablers and a range of mechanisms which are central to the delivery of the vision, including the critical need for continued and enhanced support for research and development.

Railway infrastructures are mainly considered from the perspective of an intelligent management of the life-cycle of assets in a whole-life asset approach. This means more value should be generated by fewer physical assets by maximising their utilisation over their whole life-cycle, significantly reducing the total cost of ownership. Intelligence is at each level of the system to ensure flexibility and real-time responsiveness. New materials and digitalised manufacturing processes produce assets that are inherently more reliable and have significantly reduced maintenance requirements. Assets communicate automatically with all actors across the value chain involved in safe and reliable operations (manufacturers, operators, engineering and maintenance contractors, etc) allowing optimised dispatching of robotic repair equipment, product improvement and automated traffic adaptation to asset status.

ERTRAC. Strategic research agenda. Input to 9th EU framework programme

ERTRAC highlights the important opportunities that the upcoming innovations in road transport offer: major transformations that are ahead of the European mobility system, with alternative energies, electrification, automation, digitalisation, and the sharing economy. EU Member States must work together to take advantage of the potential these innovations provide to develop Europe-wide solutions, get technology leadership and keep research excellence, production and jobs in the EU.

In the 3rd part 'Ensure an efficient and resilient road transport system', the vision is expressed as
Infrastructure and traffic management provide high efficiency road network services at a competitive cost with minimized congestion, regardless of actual conditions and disturbances. (…)
Performance based standards determine access of freight vehicles to the road network.
Physical and digital infrastructure services across Europe are appropriately equipped for automated vehicles.
Infrastructure services across Europe are on a 'pay as you use' basis.
Construction and maintenance practices are automated, leading to high cost-efficiency and minimal works to related safety risks and congestion.

Strategic research agenda for the European waterborne sector (January 2019)

The WATERBORNE technology platform has been set up by its members as an industry-oriented platform to establish a continuous dialogue between all waterborne stakeholders, such as classification societies, energy companies, infrastructural companies, environmental non-profit organisations, manufacturers, research institutes, shipyards, ship-owners, waterway and port operators, universities, fisheries and citizen associations, as well as European institutions and EU Member States.

WATERBORNE proposes a 2050 scenario for the waterborne sector, defining three missions:

1. transform waterborne transport,
2. develop European leadership and new business models for blue growth sectors,
3. integrate shipping and inland navigation into seamless port and logistics operations.

This last mission integrates port operations, including maritime and hinterland logistics and port infrastructure.

ERTRAC-ERRAC-WATERBONE-ACARE-ECTP (June 2013)
Roadmap for cross-modal transport infrastructure innovation.
Towards a performing infrastructure.
A coordinated approach to addressing cross-modal infrastructure issues for an integrated European transport system.

An **ERTRAC-ERRAC-Waterborne-ACARE-ECTP Joint Task Force** stressed that the need for R&I actions and set a guiding goal for 2030: 'By 2030, R&I should enable an improvement of 50% in infrastructure performance, risk and cost versus a 2010 baseline as well as enable seamless door-to-door services for passengers and freight by 2030'.
Three R&I domains were proposed: (1) construction and maintenance; (2) supporting systems and services; (3) government, management and finance.

Roadmaps defined by European projects

The following projects are recognised for having proposed relevant R&I roadmaps for the transport infrastructure.

The **REFINET** coordination and support action (CSA) delivered a shared vision and a REFINET strategic innovation plan, where the different levels of development of the transport infrastructures in the European countries were addressed with two complementary scenarios:

- maintenance and upgrading of already existing transport infrastructures,
- development of new transport infrastructures.

REFINET also produced the TI-Tech Mapper Platform (a web tool to analyse and map transport infrastructure technologies across Europe) which is publicly available. It makes use of data collected on: (i) best practices, (ii) technologies with high potential, and incoming technologies, (iii) innovations from research and development projects, etc. TI-Tech presents results in a format that can be used to provide support in analysis, decision-making, planning to stakeholders such as contractors and construction companies, transport infrastructure operators and managers, public bodies such as ministries, policy makers, research and academia.

The 'Infrastructure Cloud' initiative was also developed as part of the project, bringing together stakeholders from all transport modes belonging to all life-cycles of the infrastructure.

Two other Horizon 2020 CSA projects, USE-iT (Users, Safety and security and Energy in Transport infrastructure) and FOX (Forever Open Cross (X) modal infrastructure) were developed in parallel with REFINET. The USE-iT project focused on the operation of transport infrastructure across modes and cross-modal transfer, while FOX focused on the life-cycle of the physical transport infrastructure covering all modes. The work was directed to make the results of these three projects converge and feed back into the FORx4 programme, thus delivering an integrated roadmap with the results of the three projects.

SETRIS followed-up on previous work undertaken by the five European technology platforms by updating and completing their existing strategic research and innovation agendas (SRIAs), roadmaps and implementation plans, using a new, coordinated and integrated approach.

International initiatives

The OECD and IEA provide regular insights, analysis, synthesis about transport and the associated infrastructure.

As an intergovernmental organisation with 60 member countries, the OECD's International Transport Forum (ITF) acts as a think tank for transport policy and organises the annual summit of transport ministers. ITF covers all transport modes and works for transport policies that improve people's lives. ITF fosters a deeper understanding of the role of transport in economic growth, environmental sustainability and social inclusion and seeks to raise the public profile of transport policy.
Recent publications include:

- ITF Transport Outlook 2019 (22/5/2019). This publication provides an overview of recent trends and near-term prospects for the transport sector at a global level, as well as long-term projections for transport demand to 2050. The analysis covers freight (maritime, air, surface) and passenger transport (car, rail and air) as well as related CO2 emissions, under different policy scenarios. It highlights four policy insights that should be strongly considered: (1) better planning tools improve adaptability to uncertainties; (2) transport policy must anticipate disruptions that originate outside the sector; (3) transport systems will benefit from policy frameworks that foster innovation; and (4) more ambitious policies are needed to stop the growth of CO2 emissions from transport.
- Good Governance for Critical Infrastructure Resilience (17/4/2019). This report looks at how to make critical infrastructure more resilient in a dynamic risk landscape, and discusses policy options and governance models to promote up-front investments in resilience. Based on an international survey, the report analyses the progressive shift of critical infrastructure policies from asset protection to system resilience. The findings are reflected in a proposed Policy Toolkit for the Governance of Critical Infrastructure Resilience, which can guide governments in taking a more coherent, preventive approach to protecting and sustaining essential services.

IEA works to ensure reliable, affordable and clean energy for its 30 member countries and beyond and is guided by four main areas of focus: energy security, economic development, environmental awareness and engagement worldwide. IEA conducts a broad range of transport research and analysis, focusing on ways in which countries can improve the sustainability of their transport systems. It gives policy advice to governments on the effectiveness of implementing advanced technologies, improving fuel efficiency and shifting to lower-carbon fuels and transport modes, with their respective infrastructure for alternative fuel being included.
IEA publishes several documents that are periodically updated, including the World Energy Outlook (last edition 2018) and the Energy Technology Perspectives Model (last edition in 2017).

Cross-modal programmes

The roadmaps for cross-modal transport infrastructure mentioned previously that were drafted by the main ETPs concerned by transport infrastructure were key to promoting more coordination between the different modes at European level. Pooling efforts at national, EU and international or world levels would speed up implementation of R&I results in a sector traditionally separated by modes and countries.

Below are relevant initiatives which have promoted cooperation across different modes of transport.

ERA-NET Plus Infravation

In order to deliver the full benefits of research and development activities in the transport infrastructure sectors, Infravation grouped together funding from the Netherlands, Denmark, France, Germany, Iceland, Israel, Italy, Norway, Spain, Sweden, the United States and the EU into one common transnational call framework, in order to fund joint research projects.

The 2014 call was initiated as a pooled research fund to develop transport infrastructure innovations which addressed the challenges identified in the European Commission's White Paper on Transport: Smart, Green and Integrated Transport. The objective of the call was to enable a high-quality infrastructure offering high service levels to the user/economy/society through solutions for both new and existing infrastructure.

To support the preparation of the 2014 call, an Infravation scoping study was conducted. It was coordinated by the Forum of European National Highway Research Laboratories (FEHRL) and involved international experts who were tasked with determining the priority areas in advanced materials and systems. The results were published in an Infravation scope document in February 2014.

Nine projects were funded (5 for roads and 4 for bridges), the last of which ended in 2018.

The involvement of the United States in the call is an example of successful international cooperation.

infra4Dfuture (i4Df)

infra4Dfuture is a 24-month project under the Horizon 2020 topic 'Infrastructure innovation for the future' that began in 2018. infra4Dfuture will develop a demand-driven overarching strategy and coordination mechanism for modernising transport infrastructure. The project will include a shared strategic vision on future infrastructure capabilities and common pathways for innovation development and implementation.
Capabilities are proposed as follows:

- infrastructure optimally meeting end-user needs,
- infrastructure meeting environmental and social sustainability needs,
- infrastructure achieving added value from digitalisation.

Facing a variety of emerging challenges, such as climate change, resilience, ageing infrastructure, maintenance, digitalisation, automation, energy and electrification, the National Transport Infrastructure Authorities (NTIA) have urgent requirements for infrastructure innovation. In view of the long cycle times in infrastructure management and the steadily mounting pressure from the challenges mentioned above, there is a need to quickly deliver ready-to-implement, cost-effective innovative solutions that match the requirements of the NTIA and jointly build the TEN-T network.

The infra4Dfuture consortium encompasses 20 partners (19 being NTIA) from 17 countries, who have joined forces to develop:

- ✓ a strategic coordination mechanism aiming to deliver concerted cooperation and collaboration across a portfolio of relevant European and national innovation programmes and initiatives; and
- ✓ a shared strategic vision on future infrastructure capabilities, each capability encompassing a series of innovation focus areas for innovation.
- ✓ The initiative is supported by the Conference of European Directors of Roads (CEDR) and the European Rail Infrastructure Managers (EIM).

National programmes

During the elaboration of this roadmap, the group of experts developed a survey with the Commission's support to provide inputs to draft the current infrastructure STRIA roadmap. Several Member States provided information about their transport infrastructure strategies and dedicated research activities.

AUSTRIA

Austria's transport infrastructures are supported by the Austrian Ministry of Transport and Innovation Technology in the following priority areas:

- Automated mobility, Austrian Action Programme on Automated Mobility 2019-2022;
- Electromobility, National Strategic Framework 'Clean Energy in Transport';
- Road safety, road safety programme;
- Overall transport scheme;
- Expansion plan for federal transport infrastructure.

R&I is supported through various programmes, including the following.

Mobility of the Future - The Research, Technology and Innovation Programme for Mobility 2012–2020
'Mobility of the Future is a mission-oriented research and development program to help Austria create a transport system designed to meet future mobility and social challenges by identifying and refining middle-to long-term improvement ideas. The program takes a comprehensive and multidimensional approach to research because mobility is an extremely complex subject and is closely related to many fundamental social challenges.'
'Transport infrastructure' is one of the four specific research themes, the others being 'personal mobility', 'goods transport' and 'vehicle technologies'.

Aid Scheme for Green Inland Waterway Vessels
'The Aid Scheme for Green Inland Waterway Vessels programme (*Förderprogramm umweltfreundliches Binnenschiff*) has been developed as part of the implementation of the National Action Plan for the Danube. The Austrian Federal Ministry of Transport, Innovation and Technology is committed to assisting companies with the environmentally friendly modernisation of their fleets and supporting them with the implementation of new technologies.'

TAKE OFF - The Austrian aeronautics research and technology programme
'The Austrian Aeronautics Programme TAKE OFF is designed to maintain the competitiveness of the Austrian aeronautical industry and its suppliers by generating specific expertise and networking the relevant industrial, university and non-university actors. The programme supports the establishment of strategic partnerships at national, European and international level and the development of new markets. This approach is designed to increase turnover of the Austrian aeronautical sector, secure high-tech development and production in Austria and create high-quality jobs in the long term.'

BULGARIA

'The Integrated Transport Strategy for the period until 2030' supports the development of Bulgaria's transport infrastructure, which is managed by the Bulgarian Ministry of Transport and Innovation Technology.
'The strategic objectives of the transport policy for the period until 2030 are:

- Increasing the effectiveness and competitiveness of the transport sector;
- Improvement of the transport connectivity and access (internal and external)
- Limiting the negative effects of the transport sector development.

The strategic priorities of the transport sector are as follows:

- Effective maintenance, modernization and development of transport infrastructure

- Improvement of the management of the transport system
- Development of intermodal transport
- Improvement of the conditions for implementation of the principles for liberalization of the transport market
- Reduction of the consumption of fuel and increasing the energy efficiency of transport
- Improvement of the connectivity of the Bulgarian transport system with the Single European transport space
- Ensuring quality and easily accessible transport in all regions of the country
- Limiting the negative effects of transport on environment and people's health
- Increasing security and safety of the transport system.'

CZECHIA

'The Transport Policy of the Czech Republic for 2014 - 2020 (with the Prospect of 2050)' is supported by the Czech Transport Ministry. A specific 'Action Plan for the Deployment of Intelligent Transport Systems (ITS) in the Czech Republic until 2020 (with the Prospect of 2050)' has been defined. This plan mentions activities in relation to transport infrastructure.
Research, development and innovation in the transport sector are supported by a specific document establishing the strategy until 2030, supported by the Ministry of Transport.

FRANCE

The Framework Law for Mobility *(Loi d'orientation des mobilités),* to be adopted by the end of 2019, addresses the need to revise transport infrastructure policies. Too many projects were not carried out in due time due to a lack of financing. This law proposes to revise the priorities and define new orientations.

Four main objectives are proposed for strategy and programming:

- reduce territorial inequalities to ensure cohesion of the territories,
- reinforce offers for daily journeys, improve the quality and safety of the transport networks,
- accelerate the energy transition, decrease emissions and favour modal share for less polluting modes,
- increase the efficiency of freight transport.

A programme to finance implementation is supporting the proposal.

GREECE

In 2015 Greece's Ministry for Infrastructures and Transport (MIT) started a process to develop a national transport plan for Greece (NTPG), which would provide the basis for sustainable transport infrastructure and service development in Greece over the medium (2027) to long term horizon (2037). The NTPG has been developed with technical support from the European Commission's structural reform support service (SRSS) and covers all transport modes (road, rail, maritime, air and intermodal/logistics sectors) over 20 years (2017-2037). An evaluation was carried out of the significant impacts and the measures that will be taken to ensure efficient and timely implementation.

The NTPG reinforces and complements other strategic actions, including the national strategic framework for road safety 2011-2020, the National ITS Strategy 2015-2025 & National ITS Architecture 2016-2025, the National Railway Business Plan 2016-2020, the National Port Strategy 2013-2018, as well as the National Logistics Strategy and Action Plan 2017.

GERMANY

'The 2030 Federal Transport Infrastructure Plan' is the strategic document for the development of the federal road, railway and waterways networks. It was prepared by the Federal Ministry of Transport and Digital Infrastructure (BMVI).

High-capacity transport infrastructures are the basis of smooth mobility in passenger and freight transport. Traffic growth increases the need for structural maintenance and upgrading.
Consequently high-capacity transport networks are the prime objective.

Information about the research programmes of the Federal Ministry of Transport and Digital Infrastructure / *Gesamtforschungsprogramm des Bundesministeriums für Verkehr und digitale Infrastruktur* is available on the Ministry's website.

IRELAND

Ireland's transport and mobility strategy is developed in the relative parts of two main documents of the global 'Project Ireland 2040': the National Development Plan (2018) and the National Planning Framework, supported by the Government of Ireland.
For mobility, the country's national development plan aims to deliver a public transport network providing high-quality passenger interchange points, facilitating convenient transfer between efficient public transport services and integrating these services. All the planned investment in combined public transport will give the travelling public more choice and improve their experience. It will connect more people with more places and ease congestion in Ireland's cities.
The country's climate policy, including mitigation, adaptation and resilience, is supported in a multimodal view by several plans: the National Mitigation Plan (2017), the National Policy Framework on Alternative Fuels Infrastructure for Transport in Ireland: 2017 to 2030 (2017), Developing Resilience to Climate Change in the Irish Transport Sector (2019).

ITALY

Italy's strategies for the country's transport infrastructure are presented in various documents and managed by the Ministry of Transport and infrastructure.
The annex on infrastructure to the economic and finance document DEF 2019 defines the strategies for the maintenance and safety of the country's road and rail networks, with sustainable and electric road mobility.
Italy plays a key role in the development of a European transport strategy based on intermodality and an integrated approach to transport infrastructures. A national and regional network of infrastructures is defined.
Innovation and digitalisation for smart roads, sustainable mobility in cities are managed under specific strategies.

MALTA

The Integrated Transport Strategy Directorate at Transport Malta has developed the National Transport Strategy, 2050 and the Transport Master Plan, 2025. Both the strategy and master plan cover all the relevant transport modes (land, public transport, sea and air) for Malta for the short, medium and long term.
It has several priority areas which include the following topics:

- ensure a high level of service of the TEN-T core and comprehensive network;
- provide alternatives to private vehicles to encourage sustainable travel patterns and reduce private vehicle demand;
- improve road safety through better research, engineering, education and enforcement;
- improve service quality and modal share along strategic routes by introducing public transport quality corridors.

POLAND

Poland's strategy for transport and mobility and the related transport infrastructure is presented in various strategic documents produced by the Ministry of Infrastructure. They are:

- Responsible Development Strategy until 2020 (with the perspective up to 2030),
- Transport Development Strategy up to 2030,
- Resolution no. 173/2017 on the adoption of the Investment preparation and implementation concept, and
- National Spatial Development Concept 2030.

Priority is given to increasing Poland's transport accessibility by launching the 'Central Communication Port for the Republic of Poland' project.

The 'Strategy of Sustainable Transport Development' supports the integration of the transportation network, changes in individual and collective mobility, and the mitigation of the negative environmental impact of transport modes. It is managed by the Ministry of Infrastructure, local authorities and transport operators.

The 'National road construction programme', managed by the Ministry of Infrastructure/General Directorate of Public Roads and Motorways, defines the development of road infrastructure.

Information about research activities can be found on the website of the *Narodowe Centrum Badań i Rozwoju*.

SLOVAK REPUBLIC

The 'Strategic Transport Development Plan of the Slovak Republic up to 2030' is managed by the Ministry of Transport and Construction.

It supports various priority areas including:

- providing equivalent access to settlements and industrial zones to support economic growth and social inclusion in all Slovak regions (national and European scale) via non-discriminatory access to transport infrastructure and services;
- increasing the competitiveness of passenger and freight transport (vs. road transport) by setting operational, organisational and infrastructural parameters leading to an efficient integrated multimodal transport system supporting the economic and social needs of the Slovak Republic;
- improved safety and security of transport, leading to sustainable safe mobility on safe infrastructure, the introduction of new technologies/processes using preventive and control mechanisms;
- reduced negative environmental and negative socioeconomic transport impacts (including climate change) as a result of environmental monitoring, effective infrastructure planning/implementation and a reduced number of conventionally-fuelled vehicles, and use of alternative fuels.

SLOVENIA

The 'Transport Development Strategy of the Republic of Slovenia up to 2030', managed by the Ministry of Infrastructure, proposes a national strategy for planning, investments and implementation that includes all the Slovenian modes of transport in a systemic view. It is implemented by the 'Resolution on National Transport Development of the Republic of Slovenia up to 2030'. It envisages 108 measures.

A specific 'Strategy on alternative fuels development of the Republic of Slovenia' supplements the general strategy.

SPAIN

The 'Innovation Plan for Transport and Infrastructures 2018-2020', defined in coherence with Horizon 2020 and the 2017-2020 National Plan for Scientific, Technical and Innovation Research, aims at

coordinating and integrating the innovation activities of the companies and institutions of the Ministry of Public Works. The plan also seeks to promote open innovation, reinforcing collaboration with universities and the private sector.

The actions and initiatives presented in this plan are based on four strategic areas or dimensions: digitalisation, internet of the future, intermodality and energy transformation.

The Ministry of Public Works considers these aspects a key challenge, defining from them the four strategic strands of the plan — users' experience, intelligent platforms, intelligent routes and sustainability, and energy efficiency — on the basis of which 70 initiatives are planned from 2018 to 2020.

SWEDEN

The Swedish Government plan for infrastructure is detailed in several documents from different authorities: *Trafikverket,* the Swedish Transport Administration; *Transportstyrelsen,* the Swedish Transport Agency; *Trafikanalys*, Transport Analysis; *LFV,* the body responsible for civilian and military air traffic control in Sweden, as well as for the safety and development of Swedish air space, and *Sjöfartsverket,* the Swedish Maritime Administration.
The strategy covers the following priority areas: safety and security, mobility for all including multimodality, industrial competitiveness through governance and/or business models, climate and sustainability, and digitalisation.

UNITED KINGDOM

The "Transport infrastructure efficiency strategy (TIES)", published on 6 December 2017, describes seven challenges that the Department for Transport and its delivery bodies has to address to improve transport infrastructure efficiency and provide better outcomes for transport users. It has been produced by: Crossrail, Highways England, HS2 Ltd, Network Rail, Transport for London and Department for Transport.
The seven challenges complement existing efficiency plans within each transport body. They also support wider government initiatives, such as the industrial strategy, the construction sector deal, the Transforming Infrastructure programme (TIP) from the Infrastructure Project Authority (IPA) .
The seven core challenges addressed to deliver efficiencies are:

- To judge strategic choice and trade-offs based on whole life costs and wider benefits.
- To improve the way the projects are set up in order to maximise value and prevent inefficiency throughout delivery.
- To create a transport infrastructure performance benchmarking forum to share best practice and innovation.
- To establish a common approach to estimating in order to improve cost confidence and assurance.
- To promote long-term, collaborative relationships with industry to reduce transaction costs in procurement and maximise innovation.
- To challenge standards in order to enable innovation and drive efficiencies.
- To exploit digital technologies and standardise our assets in order to enable the adoption of best practice from the manufacturing sector, such as off-site construction.

ANNEX 2: INTERDEPENDENCIES WITH OTHER STRIA ROADMAPS

(PLEASE REFER TO EXCEL FILE)