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# Research Theme Analysis Report

# Transport Infrastructure

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Research Theme Analysis Report

# Transport Infrastructure

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# Executive summary

*This is the third Research Theme Analysis Report produced under the Transport Research & Innovation Portal (TRIP) continuation project for the European Commission's Directorate-General for Mobility and Transport (DG-MOVE), which began in November 2014. It covers the Transport Infrastructure research theme.*

The purpose of TRIP is to collect, structure, analyse and disseminate the results of European Union (EU) supported transport research, research financed nationally in the European Research Area and selected global research programmes. The TRIP web portal can be found at <http://www.transport-research.info>

The purpose of this Research Theme Analysis Report is to provide an overview of research performed (mostly) in the EU collated by TRIP, providing a view across many projects that fall under the theme. It reports a robust and thorough assessment of the reported results from the research projects, giving scientific and policy perspectives.

For the purpose of this review, the theme of Transport Infrastructure has been divided into six sub-themes (identified by considering the life-cycle of infrastructure) and the assessments performed within each sub-theme as well as across the complete theme. The sub-themes considered are:

- planning;
- assessment;
- pricing, funding and financing;
- construction;
- management and governance;
- monitoring and maintenance.

The key findings from a policy perspective are:

- EU policy relating to transport infrastructure has continually evolved and strengthened, as lessons from previous policy frameworks have been learnt or in response to new developments;
- the current policy framework for the Trans-European Networks – Transport (TEN-T), which includes the revised TEN-T Guidelines and the Connecting Europe Facility (CEF), is comprehensive and

aims to improve the delivery of intermodal integration and to contribute to the EU's climate goals;

- policy relating to infrastructure charging has been evolving constantly, although the implementation in practice still falls short of the high-level objective of fair and efficient pricing;
- regulatory action on safety has been more comprehensive for some modes than others, but EU policy provides an appropriate policy framework, taking account of subsidiarity principles;
- the EU policy framework for intelligent transport systems (ITS) has been more recent, and has been proactive in providing the appropriate policy frameworks and in supporting the development and implementation of the applications (e.g. under the CEF).

The key findings from a scientific perspective are:

- The focus of the successive EU research programmes has developed in parallel with the policy framework and associated technological and operational developments.
- Research on the planning of transport infrastructure has contributed to practice, particularly in relation to how to plan better for sustainable transport, including the appropriate consideration of land use effects. Research on the TEN-T network has evolved with the policy framework, as the focus is now on planning an interconnected, multimodal transport network that goes beyond the borders of the EU. Local sustainability impacts (such as those on biodiversity, landscape fragmentation and the pollution of soil and water) have been the subject of national research.
- There is a clear link between research and practice with respect to the appraisal and evaluation of transport infrastructure. The need to appraise and evaluate infrastructure better has resulted in research aimed at improving the various assessment methodologies used and how they are linked, and the consideration of wider economic and environmental impacts.
- A focus of research on pricing has been the internalisation of the external costs of transport. This has a clear link to policy in the context of delivering fair and efficient transport pricing. An important element of the research on transport pricing has been on user acceptance and the use of revenues, which are closely related. Research has also looked at how



best to phase-in changes to the structure of transport pricing. Research on the financing of transport has focused on alternative ways of financing large projects in particular, and on the challenges of using private finance and meeting the objective of fair and efficient pricing.

- Research on the construction of transport infrastructure has looked at various relevant aspects, particularly the design of infrastructure and the materials used in its construction, including the use of recycled materials. Many of these projects have direct practical applications as they have responded to the wider needs of improving the quality of infrastructure, reducing costs and improving environmental performance. More recently, attention has also turned to ancillary infrastructure (e.g. those that support the use of vehicles using alternative powertrains).
- Projects concerned with the efficiency of the operation of transport infrastructure tend to focus on a single mode or on a specific type of intermodal connection, such as around a port. Research concerning interconnectivity and interoperability tends to focus on identifying missing links or barriers to delivering these aims and then identifying possible solutions. Projects that aim to improve the performance and resilience of infrastructure in the face of extreme weather events, and safety and security challenges, focus on the design and operation of infrastructure. However, some have also looked at strategies for responding to events as they occur.
- Increasingly, research is looking at the role of ITS and other technologies in the management of transport infrastructure, including its monitoring and maintenance. New ways of repairing infrastructure and of developing infrastructure management tools have also been the subject of research.

The main recommendations for future research are:

- For most aspects of transport infrastructure covered in this report, research will be needed to respond to developments in technology and to wider social trends, including environmental issues and the changing demands of users. Technological developments will also have an impact on the way infrastructure is used, which is also likely to require dedicated research.
- With respect to planning, research will be needed to ensure a common understanding and awareness of new sustainable planning concepts and practices at all levels of government.
- There is a need for research to improve various aspects of the appraisal and evaluation of transport infrastructure. There is a need to understand the wider economic effects of infrastructure better, improve ex-post evaluation methodologies to improve learning from experience and enhance the linkages with ex-ante evaluations.
- More research is needed to understand the implications of different forms of infrastructure finance – from public-private partnerships (PPPs) to projects financed by revenues – on the ex-ante evaluation of projects and how these might be implemented in a way that is consistent with fair and efficient pricing.
- There is a need to synthesise and disseminate better the research that has been undertaken with respect to the pricing and financing of transport infrastructure. Further research

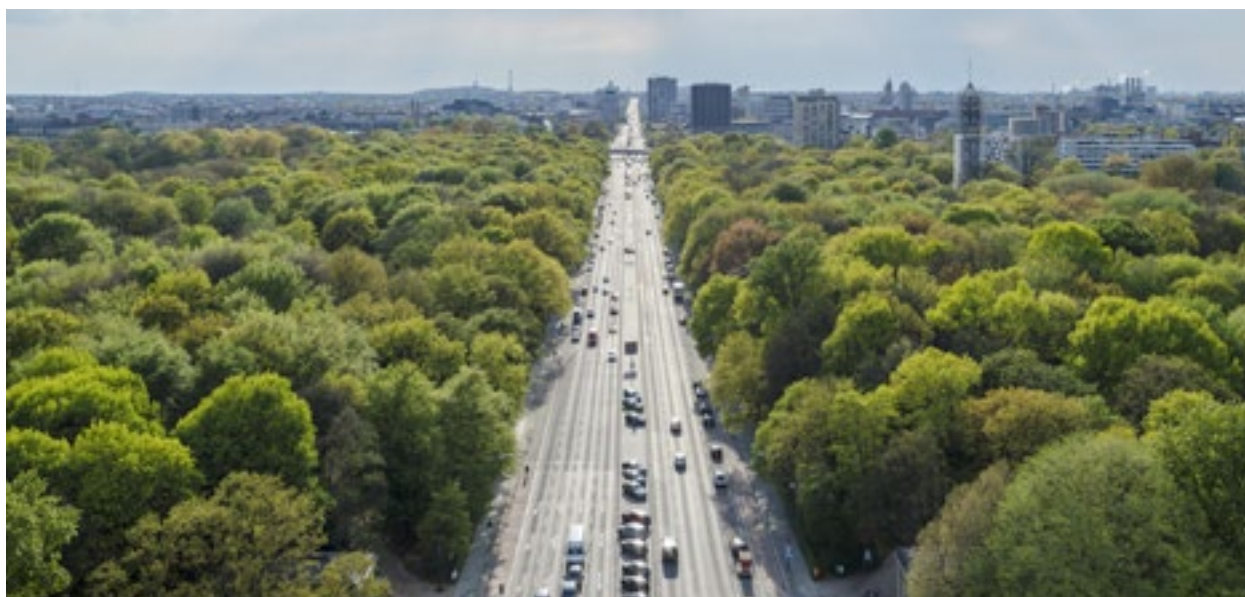
on increasing the acceptability of fair and efficient charging schemes for transport would also be beneficial.

Regarding the construction of infrastructure, research is needed to:

- accelerate construction, including of off-site construction methods;
- make infrastructure more durable and better from an operational perspective;
- reduce the disruption caused by its maintenance and to maximise the use of secondary raw materials in the construction process.
- Research also needs to focus on improving the way in which electric vehicles are charged and connected to the grid, and on ensuring that the construction and maintenance of infrastructure takes account of developments in cooperative intelligent transport systems (C-ITS).
- The rapid developments in information and communication technologies provide many opportunities to improve the way in which infrastructure is managed, many of which will require research into how best to apply these technologies while delivering wider social objectives.

The main recommendations for future policy development are:

- Planning policy needs to look at the further integration of the various land use and transport planning instruments, while reflecting the different transport patterns across Member States. There is also a need for policy to take account of the interfaces between the EU's TEN-T network and the networks of neighbouring countries with a view to optimising international transport corridors and traffic flows.
- There is a need for policy to support the development and application of ex-ante evaluations and ex-post evaluations.
- Policy development in transport pricing needs to focus on achieving a more streamlined and standardised approach to infrastructure charging based on well-researched criteria to improve the implementation of fair and efficient pricing structures.
- Improved design standards and green public procurement could be beneficial to support research and innovation in construction. There might be scope for policy action to ensure that the contribution of road surfaces to noise pollution is addressed (e.g. by setting appropriate standards).
- The current TEN-T/CEF framework should be monitored to ensure that it contributes to improving the efficiency, interconnectivity and interoperability of the EU's transport network. Policy in the area of resilience to extreme weather events, safety and security could take the form of relevant standards, depending on the mode and infrastructure concerned.
- The policy framework for ITS will need to be kept under review as the technologies and their range of applications develop. Appropriate standards to ensure interoperability and security might be necessary at some point.



# 1 Introduction

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The purpose of TRIP is to collect, structure, analyse and disseminate the results of European Union (EU) supported transport research, research financed nationally in the European Research Area and selected global research programmes. The TRIP web portal can be found at <http://www.transport-research.info>

This Research Theme Analysis Report gives an overview of research performed (mostly) in the EU collated by TRIP, providing a view across many projects that fall under the theme title. It provides an assessment of the reported results from these projects and offers perspectives from scientific and policy points of view.

This assessment aims to consider:

- overall trends in transport infrastructure research, including key results;
- the alignment of the research with current policy;
- policy implications of the results from the research;
- any gaps within the research theme.

The theme for this analysis was decided in consultation with DG-MOVE.

The assessments for this analysis have been performed on a number of sub-themes within the theme of Transport Infrastructure. The projects identified have been clustered under these sub-themes. The analyses of the trends and gaps have been performed across the projects in the sub-themes

and across the full transport infrastructure theme. The set of sub-themes, selected following initial assessments of the projects and in consultation with DG-MOVE, consists of:

- planning;
- assessment;
- pricing, funding and financing;
- construction;
- management and governance;
- monitoring and maintenance.

The assessments of trends and gaps are mainly based on selected projects within the TRIP database.

Projects funded by the European Commission align with EU policy through the funding and selection process. As such, the trends identified from these projects may not necessarily be representative of those from further afield.

Section 2 of this report presents the policy and research context of transport infrastructure and Section 3 describes the scope of this theme analysis. The subsequent sections then present reviews of the individual sub-themes (as specified above), and the research activities and outcomes. Conclusions and recommendations are then presented at the end of the report.

The preparation of this report has involved the analysis of a large number of projects related to the theme of Transport Infrastructure. Most were identified from the TRIP database, others were identified from other sources. To enhance readability, the text of this report refers to projects by their standard acronyms (where an appropriate one exists); more details of the projects, including the full titles, are given in the tables at the end of each sub-theme section.



## 2 Policy and research context

### 2.1 Transport infrastructure in European transport policy

Transport infrastructure is a key component in economic development. In a direct manner, transport infrastructure plays a role as a capital input into production and wealth generation. Indirectly, transport infrastructure contributes to economic development through a multitude of channels, including enabling productive private investment, creating new activities (supply chains) and reshaping economic geography. Also, transport infrastructure is a necessary input into the production of transport services which, in turn, are necessary to allow for the market exchange of final goods and inputs (including labour), or for broader welfare benefits (e.g. travel time savings). Given its central role, transport infrastructure is often referred to as the backbone of a modern economy (ITF, 2013). However, all these positive impacts are strongly dependent on an efficient use of the infrastructure, especially in highly infrastructured contexts.

Traditionally, development of transport infrastructure has had a primarily national focus. However, the smooth functioning of the internal market; an economic, social and territorial cohesion; and improved accessibility across the European Union (EU) are overarching policy objectives that, over the last two decades, have provided the basis for an increasing role of the EU in this area (van Essen et al., 2012).

Over the years, EU policy on transport infrastructure has covered a wide range of topics. For the purpose of this thematic review, scene setters have been identified to help provide a general understanding of the way in which the EU policy on transport infrastructure has evolved over time. They include:

- Trans-European Network – Transport (TEN-T) corridors and the evolution of the TEN-T policy;
- infrastructure charging policy;
- policy on transport infrastructure safety;
- policy on intelligent transport systems (ITS) supporting transport infrastructure development.

#### 2.1.1 TEN-T corridors and the evolution of the TEN-T policy

The TEN-T concept has its origins in 1992 when, under the impulsion of the Treaty on European Union, the European Commission released the White Paper 'The Future Development of the Common Transport Policy' (European Commission, 1992). Besides providing a comprehensive vision of a transport policy conceived at the European scale for the first time, this White Paper defined the development

of the TEN-T networks as an EU policy goal, calling for the interconnection and interoperability of national networks.

Further developments occurred in 1994 when the European Council identified the so-called 'Essen projects'. In 1996, the first regulation establishing rules for financial support for the TEN-T network ((EC) No. 2236/95) and the first guidelines for the TEN-T network development (Decision No 1692/96/EC) were adopted with the purpose of fuelling the development of the initial list of Essen priority projects.

In 2004, Decision No 884/2004/EC revised the existing TEN-T regulatory framework by identifying 30 priority corridors.

Through the 2011 TEN-T revision, later modified in 2013 with the adoption of Regulations (EU) No. 1315/2013<sup>1</sup> and (EU) No. 1316/2013<sup>2</sup>, a new planning concept established a two-layer network (Doll et al., 2015):

- a top layer, which is made up of the TEN-T core network, and comprises infrastructure nodes and links of highest European importance to be completed by the year 2030;
- a bottom layer, which is defined by the strategic networks designed by each Member State as defined in 2004 and called the comprehensive TEN-T network.

This revision aimed to adapt the TEN-T concept better to the newly emerged challenges of growing mobility needs, financial scarcity, urban development, scarcity of fossil fuels, climate change and environmental protection.

As discussed in 2011 by the Centre for European Policy Studies (CEPS, 2011), the way in which the TEN-T projects were designed originally facilitated neither an effective integration between diverse transport modes nor an optimal functioning of transport elements (infrastructure, nodes, information and communications technology applications, network services, and operational and administrative procedures). These different elements should work in combination to promote co-modality, modal shift, and an efficient and effective organisation of the whole transport system. Moreover, CEPS also argued that the TEN-T policy was driven neither by climate change mitigation and adaptation objectives nor by an effective transport pricing system, hence undermining the steering of infrastructure investment (CEPS, 2011).

Therefore, the 2011 revision was an attempt to overcome these major backlogs. It also aimed to align EU efforts along the 'common project' of a forward-looking transport network that displays an effective multimodal dimension, which enables sustainable, safe and high-quality transport services across the modes.

<sup>1</sup> Regulation (EU) No 1315/2013 of 11 December 2013 on Union guidelines for the development of the trans-European transport network and repealing Decision No 661/2010/EU.

<sup>2</sup> Regulation (EU) No 1316/2013 of 11 December 2013 establishing the Connecting Europe Facility, amending Regulation (EU) No 913/2010 and repealing Regulations (EC) No 680/2007 and (EC) No 67/2010.

To support this vision, the Connecting Europe Facility (CEF), a new EU instrument, was introduced as an integral part of the revised TEN-T policy. The goal of the CEF is to stimulate the establishment of, potentially large, financial instruments to allow the channelling of institutional investors' liquidities into infrastructure projects.

### 2.1.2 Infrastructure charging policy

Establishing a common framework for the efficient pricing of transport infrastructure is a topic largely covered by European transport policy. Indeed, fair and efficient pricing is seen as an essential component of a transport policy that can contribute significantly to reducing some of the main transport problems.

In 1995, the European Commission released the Green Paper 'Towards fair and efficient pricing in transport' (European Commission, 1995). This advocated charging users for infrastructure costs (i.e. costs related to construction, maintenance and operating of infrastructure) and for the external costs of their journeys (notably congestion, accidents and environmental problems) to reduce transport problems and to make Europe's economy more competitive and sustainable.

Since then, the EU strategy to internalise external costs from transport, further confirmed in the 2011 White Paper 'Roadmap to a Single European Transport Area. Towards a Competitive and Resource Efficient Transport System' (European Commission, 2011), has called for marginal cost charging for externalities to be applied in all transport modes. Steps have also been taken to introduce common principles of transparency; non-discrimination; cost-relatedness; and the environmental modulation of infrastructure charges in the road, rail, airport and seaport sectors.

The EU has been working for a considerable time towards the development of a common framework for a fair and efficient road infrastructure charging system, covering infrastructure and external costs. After the adoption of Directive 1999/62/EC<sup>3</sup> (known as the 'Eurovignette' Directive), infrastructure costs in EU Member States were, to some extent, reflected in the charges applied. Nonetheless, the objective of full-cost pricing (i.e. recovery of full infrastructure costs and external costs) across the EU remained unachieved.

The subsequent reviews of the Eurovignette Directive raised the prospect of a more widespread pricing for the use of infrastructure. This review process resulted in the adoption of Directives 2006/38/EC<sup>4</sup> and 2011/76/EU<sup>5</sup>.

Directive 2006/38/EC introduced further options for varying infrastructure charges to achieve policy objectives linked to the environment, congestion and management of traffic flows – albeit with a maximum ceiling on the degree of variations.

Directive 2011/76/EC allows Member States to levy, on top of infrastructure charges, an external cost charge related to air and noise pollution from road traffic. It also allows Member States

to vary charges to reduce congestion and optimise the use of infrastructure.

Rail track charging is governed by Directive 2001/14/EC – this has been updated through a number of 'railway packages' since 2001 (Doll et al., 2015). The approach established by Directive 2001/14/EC requires charges to at least recover marginal infrastructure costs with national governments funding the difference between the social marginal costs and the full, long-run financial cost paid by the infrastructure manager. The principles set by the Directive have been implemented differently in national legislation, not only with regard to the pricing structures, but also to the basis of the charges, the level of internalisation and the level of charges imposed (van Essen et al., 2012a). The recast of the first railway package and the proposal for a fourth railway package foresee a differentiation based on noise emission reductions (Doll et al., 2015).

In aviation, the policy development for airport charges led to the adoption of Directive 2009/12/EC<sup>6</sup>. The Directive complements the policies on airport charges drawn up by the International Civil Aviation Organization (ICAO).

Finally, for seaports, the issue of transport externalities and their internationalisation first appeared in the 1991 White Paper on Transport and was later included in the Green Paper on ports and maritime infrastructure of 1997 (Haralambides and Acciaro, 2014). After two failed attempts in 2001 and 2004 (Milchenko, 2015), further development occurred in 2007 when the European Commission circulated the 'Communication on a European ports policy' (European Commission, 2007a). In this, it mentioned, among other things, that the European Commission should expand best practices in port charges in Member States. Finally, the European Commission presented the achievement of fair market access as Action 2 in the 'Communication on ports and the ports services regulation' that was published in 2013 (European Commission, 2013c).

### 2.1.3 Policy on transport infrastructure safety

Safety is of primary concern for any transport system and is an integral element of EU transport policy.

Road transport is the most widely used means of travel and a primary cause of accidents. Therefore, it is not surprising that the European Commission has been very active in promoting initiatives to decrease the number of fatalities caused by road accidents.

A strong focus on road safety infrastructure management has been recommended at the EU policy level since the adoption of the White Paper on Transport Policy in 2001 (European Commission, 2001) and the European Road Safety Action Programme (ERSAP) 2003–2010 (European Commission, 2003) when the ambitious objective to halve the number of fatalities in the EU-15 from over 40 000 to 20 000 by 2010 was launched. This commitment to improve road safety was renewed in 2010 (European Commission, 2010b), (European Commission, 2011).

<sup>3</sup> Directive 1999/62/EC of 17 June 1999 on the charging of heavy goods vehicles for the use of certain infrastructures.

<sup>4</sup> Directive 2006/38/EC of 17 May 2006 amending Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures.

<sup>5</sup> Directive 2011/76/EU of 27 September 2011 amending Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures.

<sup>6</sup> Directive 2009/12/EC of 11 March 2009 on airport charges.

Accomplishing such an objective requires the implementation of a wide range of safety measures, not least to increase the potential that road infrastructure safety measures offer to significantly reduce road deaths (TML, 2014). To this end, the general framework for road infrastructure safety management comprises two pieces of EU legislation (i.e. Directive 2004/54/EC on minimum safety requirements for tunnels in the trans-European road network<sup>7</sup> and Directive 2008/96/EC on Road Infrastructure Safety Management<sup>8</sup>). The two Directives have different, but complementary, approaches with respect to road infrastructure safety. On the one hand, Directive 2004/54/EC is based on the mandatory application of detailed technical provisions aiming to:

- ensure minimum safety requirements in road tunnels so guaranteeing a high, uniform and constant level of security, service and comfort;
- prevent critical events and provide protection when accidents do occur.

On the other hand, Directive 2008/96/EC<sup>9</sup> introduces a comprehensive system of road infrastructure safety management with the principal goal of establishing procedures to ensure that safety is integrated in all phases of the planning, design and operation of road infrastructure (TML, 2014), (SDG, 2014). The Directive applies only to the TEN-T network, but

encourages Member States to apply its provisions to the rest of the network constructed using EU funding in whole or in part and many of them have done so (TML, 2014), (SDG, 2014).

Safety is also at the heart of the EU rail sector. A common regulatory framework for railway safety was set with the adoption of Directive 2004/49/EC<sup>10</sup> (also known as the 'Railway Safety Directive'), which established a framework for harmonising national safety rules. Secondary legislation in the railway safety sector has been developed and the implementing acts (common safety indicators, common safety methods, common safety targets and certification of the entities in charge of maintenance for freight wagons) required by the Railway Safety Directive have also entered into force (European Commission, 2014). Equally important, the European Railway Agency (ERA), which was established in 2004, is a cornerstone of the EU strategy for railway safety. It supports national safety authorities and national investigation bodies in their tasks and provides evidence for policy actions at the EU level. It also develops and promotes the common safety framework as a means of achieving an open railway market in the EU. Recent initiatives from the European Commission, such as the technical pillar of the 4<sup>th</sup> Railway Package and the development of a Platform of Rail Infrastructure Managers in Europe (PRIME), have real potential to bring further safety improvements (ERA, 2014).



<sup>7</sup> Directive 2004/54/EC of 29 April 2004 on minimum safety requirements for tunnels in the Trans-European Road Network.

<sup>8</sup> Directive 2008/96/EC of the European Parliament and of the Council of 19 November 2008 on road infrastructure safety management.

<sup>9</sup> *ibid.*

<sup>10</sup> Directive 2004/49/EC on safety on the Community's railways and amending Council Directive 95/18/EC on the licensing of railway undertakings and Directive 2001/14/EC on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification.

Safety is also a central tenet of EU regulatory effort in aviation. So far, Europe has been successful in maintaining a high level of safety (European Commission, 2014) and remains, alongside the United States of America, the safest region in the world for air passengers. This good safety record must be put in the context of the regulatory achievements of the past decade. A single regulatory system has been put in place and the European Aviation Safety Agency (EASA) has been established as the EU's technical agent for aviation safety (European Commission, 2015). As part of the 'aviation package'<sup>11</sup> (European Commission, 2015), the European Commission is considering initiatives to improve the competitiveness of the EU aviation sector. The objective is to prepare the EU aviation safety framework for the challenges of the next 10-15 years and, thus, to continue to ensure safe and secure air transport for passengers, while reducing the impacts on the environment. This initiative builds on over 12 years of experience in the implementation of Regulation (EC) No 216/2008<sup>12</sup> (European Commission, 2015).

Finally, in the maritime sector, EU policy and legislation initiatives have been introduced since 1999 to improve the level of maritime safety. In 2005, to supplement the European rules concerning maritime safety and to improve the efficiency of the existing measures, the European Commission adopted the 3<sup>rd</sup> Maritime Safety package.

#### 2.1.4 Policy on ITS supporting transport infrastructure

The development of ITS supporting the deployment of transport infrastructure is another domain where EU policy development has been very active in recent decades.

In air transport, since 2004, the European Commission has worked on the development of Single European Sky ATM Research (SESAR). This is the framework aiming to improve air traffic management (ATM) performance by modernising and harmonising ATM systems through the definition, development, validation and deployment of innovative technological and operational ATM solutions. Once fully implemented, SESAR will enable a fast and easy information exchange not only between air traffic controllers and pilots, but useful messages will also be sent in real time by airline operation centres, meteorological services and airports.

For inland waterways, Directive 2005/44/EC, the framework for river information services<sup>13</sup> (RIS) was put in place. RIS are information technology (IT) related services designed to optimise traffic and transport processes in inland navigation. From a policy perspective, the development of RIS enhances the competitive edge of inland waterway transport in the supply chain. The policy importance of RIS is presented in various EU policy papers, for example:

- the European Commission White Paper 'TEN-T Guidelines';
- 'Navigation and Inland Waterway Action and Development in Europe' (NAIADES I and II);
- the Logistics Action Plan.

The railway network has introduced the European Rail Traffic Management System<sup>14</sup> (ERTMS), a unique European train control system that is designed to gradually replace the existing incompatible systems throughout Europe. Key milestones for the evolution of the policy setting were the adoption, in 2009, of the ERTMS European Deployment Plan and the signing, in 2012, of the ERTMS Memorandum of Understanding (ERA, 2012). In particular, the latter introduced Baseline 3, which provides stability and increased confidence in a system that encourages future ERTMS deployment.

For shipping, the Vessel Traffic Monitoring and Information System (VTMIS) was introduced in 2009 and completed in 2012 following the adoption of Directive 2002/59/EC<sup>15</sup>.

For road transport in Europe, there has been a number of activities in the ITS domain since the 1980s (European Commission, 2008). Examples of ITS applications include urban and motorway traffic management and control systems, electronic toll collection and route navigation.

However, there was no coherent European framework for interconnection between road and the other transport modes.

An attempt to deliver a coherent framework was proposed in 2009 with the adoption of the ITS Action Plan and, in particular, when Directive 2010/40/EU<sup>16</sup> (known as the 'ITS Directive') was brought into force. The Directive provides for priority areas<sup>17</sup> and priority actions to be implemented at the European level. It charges the European Commission to develop and adopt specifications that are subsequently binding for the deployment of the related ITS applications and services (ERTICO, 2010).

<sup>11</sup> See [https://ec.europa.eu/transport/modes/air/consultations/2015-aviation-package\\_en](https://ec.europa.eu/transport/modes/air/consultations/2015-aviation-package_en)

<sup>12</sup> Regulation (EC) No 216/2008 of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No 1592/2002 and Directive 2004/36/EC.

<sup>13</sup> [www.ris.eu](http://www.ris.eu)

<sup>14</sup> [www.ertms.net](http://www.ertms.net)

<sup>15</sup> Directive 2002/59/EC of 27 June 2002 'establishing a Community vessel traffic monitoring and information system', as amended by Directive 2009/17/EC.

<sup>16</sup> Directive 2010/40/EU of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport Text with EEA relevance.

<sup>17</sup> The six priority actions are: i) provision of EU-wide multimodal travel information services; ii) provision of EU-wide real-time traffic information services; iii) data and procedure for the provision of road safety related minimum universal traffic information free of charge for users; iv) harmonised provision for an interoperable EU-wide eCall2; v) provision of information services for safe and secure parking places for trucks and commercial vehicles; and vi) provision of reservation services for safe and secure parking places for trucks and commercial vehicles.



## 2.2 Transport infrastructure in European research programmes

Since 1984, EU-funded research has extensively supported EU policy on transport infrastructure with the overarching goal of making it increasingly sustainable, cost-efficient, accessible, safer and secure.

An examination of the individual Framework Programmes for Research and Technological Development (FPs) makes it easy to see how priorities and objectives have evolved in parallel with the policy, technological and operational developments experienced by the European transport system over time. Shaping the EU transport system (FP4 (1994-1998)), easing cross-modal interoperability and interconnectivity (FP5 (1998-2002)), enhancing sustainability (FP6 (2002-2006)), gearing up optimisation of the EU transport system (FP7 (2006-2013)) and preparing the EU transport system for the new era of smart mobility (Horizon 2020 (2014-2020)) have progressively emerged as key concepts that have heavily contributed to defining the EU transport research strategies over the past decades.

Compared to its three predecessors, FP4 represented a major quantitative and qualitative leap forward in the transport research area. For this theme, a specific programme was established under the 'first activity' to support the development and implementation of the Common Transport Policy (European Commission, 1992). During FP4, considerable efforts were devoted to prenormative and prelegislative research for developing methodologies and tools to support the assessment of impacts from large transport infrastructure projects and social marginal cost pricing. These methodologies and tools were intended to be applied primarily to support TEN-T development policies.

With FP5, research objectives and priorities for transport infrastructure were developed within two key actions ('Sustainable mobility and intermodality' and 'Innovative products, processes and organisation') under the 'Competitive and Sustainable Growth' thematic programme (European Commission, 2000). In the transport infrastructure area, FP5 set the strategic objective of easing interoperability and interconnectivity between different elements of the transport network (in particular the TEN-T network) and between different modes. Accordingly, research was performed to optimise nodal areas and terminals as they were identified as key elements of seamless intermodal networks. Research was also performed to improve the cost-efficiency of infrastructure maintenance. Also, taking stock and building upon the results obtained in FP4, FP5 further contributed to the development and implementation of interoperable ITS infrastructure and solutions across the different modes<sup>18</sup>.

Already identified as a research priority in FP5, and fully linked with the policy objectives set by the 2001 White Paper on Transport, the concept of 'sustainability' was embraced more radically in FP6 (European Commission, 2001). Embedded in FP6's 'sustainable development' action priority, transport research confronted the dominant trends highlighted in the

2001 White Paper (i.e. the high levels of growth in demand for road and air transport, unbalanced modal split, limitations on public budgets and the elimination of major transport bottlenecks) to enhance the sustainability of the transport system. This prompted lines of research that, specifically for transport infrastructure, included new technologies and concepts, advanced design and production techniques, infrastructure financing and pricing, road infrastructure safety, and further integration of ITS solutions and architectures.

FP7 was designed to gear up the optimisation of the EU transport system. Later FP7 work programmes tackled the need for combining 'hard' and 'soft' research infrastructure and, accordingly, aimed to provide the capabilities to address the newly established policy (European Commission, 2011) and the newly emerged challenges (European Commission, 2010a) in the transport domain (e.g. greening transport, increasing efficiency, reducing congestion, improving urban mobility, improving safety and security, and increasing competitiveness). Also important, as concluded by the Technopolis Group (Technopolis, 2011), the approach adopted for transport in FP7 constituted a significant improvement compared to the previous FPs. For example, it was:

- more integrated – surface transport and aeronautics now belong to the same transport programme;
- systemic – the co-modality approach is established, so tackling all modes of transport under one flag;
- holistic – linking 'soft' (e.g. regulatory, policy-related and social) and 'hard' (e.g. technology developments) issues.

This integrated, systemic and holistic approach was also visible in the EU research efforts in the transport infrastructure thematic area, where lines of research targeted the optimisation of the global efficiency and safety of the transport infrastructure.

Finally, 'competitiveness and sustainability' – which heavily shaped the 2011 White Paper on Transport – summarise the policy goals that are set by the Horizon 2020 Programme (2014-2020) for the transport thematic area. Horizon 2020 pools additional resources to the already mature research and innovation efforts in the transport domain and intends to take on the challenge to achieve a 'smart' transport system that is resource efficient, less environmentally harmful, and safe and seamless – while promoting, globally, the degree of competitiveness of the transport industries. Narrowing the analysis to transport infrastructure, Horizon 2020 identifies this sub-theme as a standalone topic, for which it acknowledges that multifaceted challenges persist (European Commission, 2013b). In particular, these relate to network and modal fragmentation, constrained public budgets, growing impacts induced by climate change, disparities across Member States in quality and availability of infrastructure, and persisting bottlenecks especially at cross-border sections. Set against these challenges, a key priority for EU research is to find innovative solutions to increase the performance, robustness and efficiency of infrastructure for all modes of transport.

<sup>18</sup> Major examples include VTMS, RIS, extension of the ERTMS towards the traffic management layers, the cost-benefit validation of the implementation of a European Air Traffic Management System and, ultimately, the development and implementation of the Galileo system.





### 3 Scope of the Transport Infrastructure theme

*The development of an efficient, seamless and sustainable transport system calls for a departure from old modally fragmented planning paradigms and for the adoption of an integrated and cross-modal approach that considers transport infrastructure as a whole multimodal entity along the full life-cycle.*

The approach to this thematic review recognises the need for a systemic approach to transport infrastructure by structuring the analysis in cross-modal terms and along the phases of a typical infrastructure life-cycle. These phases mainly consist of:

- **Planning** – in this stage, the vision and general principles guiding the conception of the transport infrastructure are laid down. Also fuelled by research outcomes, the general principles of transportation planning have considerably evolved over recent decades, moving from systematic approaches for ‘solving’ contingent transport problems to the development of holistic strategies embracing sustainability and long-term perspectives.
- **Assessment** – the ex-ante evaluation is performed before the realisation of new transport infrastructure to assess the benefits and the costs associated with the new interventions. Therefore, a proper assessment is crucial to identify expected economic, political, social and environmental impacts, and the overall sustainability of infrastructure. The assessment can also be performed after the realisation of the infrastructure (ex-post) to derive lessons learned, which will enhance future policy and projects.
- **Pricing, funding and financing** – in this stage, alternative possibilities for funding transport infrastructure are explored and evaluated. Different means of transport infrastructure funding are available and different economic principles could guide the decision-making process. Research in this field can provide improved, transparent and harmonised investment decision making at all levels, so balancing performance with cost and risk.
- **Construction** – this stage encompasses all aspects of the design and construction of the new infrastructure. Key aspects include technical design, construction techniques and materials, and the realisation of ancillary infrastructure.
- **Management and governance** – once the transport infrastructure is built, it enters the management and governance phase. The efficient management of a transport infrastructure encompasses the consideration of several aspects. These range from the constant improvement of transport operations to increasing its cost-effectiveness. They also include the enhancement of interconnectivity and interoperability of transport networks, the improvement of the resilience to extreme events, the management of safety and security issues, and the deployment of intelligent transport systems (ITS) to support the infrastructure governance.
- **Monitoring and maintenance** – proper monitoring of the condition of the infrastructure is of utmost importance in developing maintenance plans and prioritising interventions. Research in this field has investigated the adoption of innovative technologies supporting smart structural monitoring systems. These can be used to improve predictive capacity and maintenance planning of the transport infrastructure network, including the determination of the optimal balance between long-term renewal and short-term maintenance.

**Figure 3-1 Sub-themes identified within the overall research theme**



Each of the above-mentioned phases is regarded as a sub-theme within the overall Transport Infrastructure research theme.

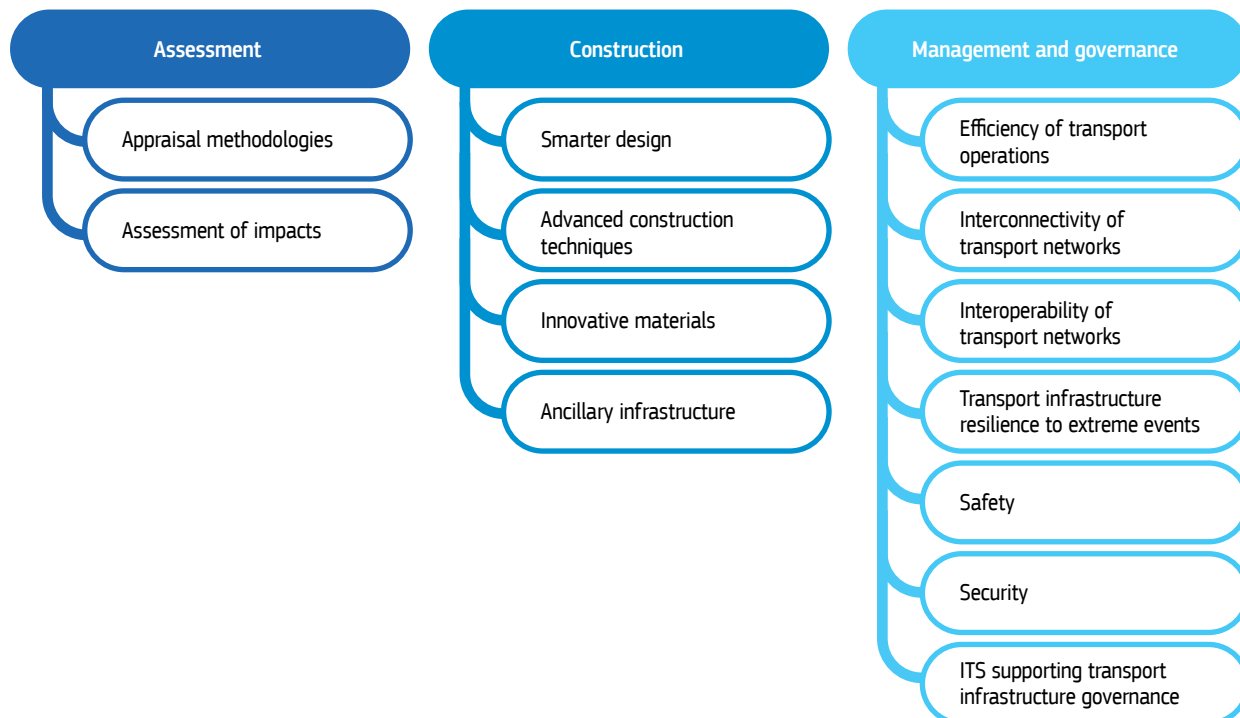
Given their multifaceted nature, three of these sub-themes are segmented further, as shown in Figure 3-2.

Strong links between the sub-themes exist. As an example, planning and ex-ante evaluation are generally two highly interlinked steps in the conception of sound and sustainable infrastructure.

Similarly, monitoring and maintenance are highly dependent on the chosen construction materials and the overall management practice, which can significantly influence the life of the infrastructure.

However, each research sub-theme is relevant for the discussion and is analysed separately in the following sections.

**Figure 3-2 Research topics covered in the sub-themes – assessment, construction, and management and governance**



## 4 Sub-theme assessments

### 4.1 Planning

#### 4.1.1 Introduction to the sub-theme

Transport infrastructure planning is a highly sensitive political topic at a national level and, increasingly, at an international level. However, transport infrastructure planning is also a central subject for research, where difficult conceptual and analytical issues are investigated and discussed.

Over the years, the integration between transport infrastructure planning and land use planning has been substantially researched. Land use and transport are interlinked as land use affects and is affected by transport policy.

Having an efficient and effective transport system relies on getting the land use planning right and planning urban or regional development relies on getting the transport access right. In particular, this is of importance at the urban level where to achieve a more sustainable transport system, concepts have been developed to embed urban mobility into a wider urban and territorial strategy (e.g. the Sustainable Urban Mobility Plans). This includes transport infrastructure, land use, spatial planning, as well as environmental policy, economic development policy and social policy (European Commission, 2013d).

##### 4.1.1.1 Overall direction of European-funded research

European research in the field of planning transport infrastructure has covered a wide range of topics, including:

- the analysis of strategic planning processes at national and international levels to create a common understanding and awareness of new, more-sustainable transport planning concepts and practices at all the levels of government (e.g. the [COST 332](#) (1996-2000) and [TRANSPLUS](#) (2000-2003) projects);
- the approach to identify, plan and develop the Trans-European Network – Transport (TEN-T) and other European transport infrastructure, which evolved from supporting a small number of disconnected priority projects to planning an interconnected, multimodal network that looks beyond the European Union (EU) borders to optimise interfaces and links with the EU's neighbouring countries (e.g. the [COST 340](#) (2002-2004), [MEDA TEN-T](#) (2003-2005), [SEB-TRANS-LINK](#) (2002-2005) and [TREND](#) (2005-2006) projects);
- the development of strategic long-term perspectives and visions of future transport infrastructure in Europe at different time horizons (e.g. [2050AP](#) (2005-2006), [LivingRAIL](#) (2012-2015) and [SPIDER PLUS](#) (2012-2015) projects).

In addition, EU research programmes have funded European Rail Research Advisory Council (ERRAC) and European Road Transport Research Advisory Council (ERTRAC) platforms.

These have been set up with the goal of bringing together transport stakeholders to foster innovation and integration in research, including the development of long-term visions for transport infrastructure at a European level.

##### 4.1.1.2 Overall direction of nationally funded projects

National research in the 'planning' thematic area has involved a large variety of topics and research issues, including:

- The analysis of the negative impacts that transport infrastructure is likely to generate in terms of landscape fragmentation and of the subsequent adverse effects that occur on the ecosystem. These include the endangerment of species and habitats, the loss of biodiversity, and the pollution of water regimes and soil.
- The development of methodological tools and guidelines to identify and overcome weaknesses of today's standard planning processes applied at the national level, while providing up-to-date knowledge to respond to the new developments to which transport infrastructure is required to adapt rapidly.

#### 4.1.2 Research activities

The relationship between transport and land use has been widely researched at EU-wide and national levels. A variety of issues, methodologies, measures and contexts have been investigated. Overall, this has significantly widened the wealth of knowledge and information that is available today, while highlighting the need for transport policies and investments to be properly coupled with land use policies and programmes if they are to be successful.

Within this context, the COST 332 project evaluated innovative institutional coordination arrangements to achieve greater coherence among the decision-making processes in the fields of transport and regional planning. Importantly, this project considerably improved the knowledge of the interactions between transport and land use policies, while developing a theoretical model, and operational conclusions and recommendations on the coordination arrangements between transport and land use policies.

The mission of the TRANSPLUS project was to identify best practices in the organisation of land use and transport policies to achieve a sustainable pattern of transport and land use in European countries. Among others, TRANSPLUS produced the following results:

- harmonisation of national land use, transport planning and policy frameworks in EU Member States;
- support to the application of the EU Environmental Impact Assessment (EIA) Directive in EU Member States;



- identifying practical criteria and a consistent set of indicators for land use, and for the impact evaluation of transport policies and infrastructure developments.

At the transport planning and land use interface, the Swiss national project '[Ex-post analysis of the spatial impact of transport infrastructure - Case study of Zurich S-Bahn](#)' (2003-2004) analysed the spatial changes that were observed in the catchment area of the Zurich S-Bahn and related this to the impacts generated by this transport infrastructure. The study also sought to gain an understanding of the causes inherent to these changes. The final goal was to produce recommendations for better monitoring of the impacts of new transport infrastructure, with a view to mitigate their environmental consequences.

The interplay between transport planning and land use also has clear impacts in terms of landscape fragmentation and has been researched at the national level. In this respect, the Swiss study '[Landscape fragmentation by transportation infrastructure in Switzerland](#)' (2005-2007) and the Czech study '[Influences of transport infrastructure on morphology and fragmentation of the landscape](#)' (2004-2008) reconstructed the distinctive ecological impacts due to landscape fragmentation as a consequence of transport planning. They concluded that such fragmentation has continued to increase during the last two decades, despite planning aimed at the preservation of large, unfragmented areas. The study drew conclusions to assist regional traffic planning and proposed new concepts for controlling landscape fragmentation according to the principles of sustainable development.

In the road sector, the [ERTRAC](#) (2003-2006), [ERTRAC II](#) (2006-2009) and [FOSTER ROAD](#) (2013-2016) projects provided a research framework to focus the co-ordination of the efforts of public and private resources to optimise research on the design, planning and integration of the more systemic aspects of the road transport system. The aim of this was to make the road transport system have less of an impact on the environment,

more sustainable in urban areas, more efficient and safer. In terms of results, ERTRAC and ERTRAC II have, in particular, contributed to coordinating the development of more cohesive strategies for transport design and planning (particularly at the local level) together with a greater appreciation of environmental and social effects.

The implication of rail development for transport and land use planning to improve the performance of the rail mode were touched upon by the LivingRAIL project. This explored the policy instruments (urban and land planning policies, and transport infrastructure planning) available for public administrations. It contributed to the identification of good practices that, as part of the LivingRAIL project, were assessed as being able to promote growth of the rail sector across Europe.

Other research projects identified new concepts for increasing the degree of competitiveness of rail freight. The TREND project contributed to a better understanding of planning approaches to rail freight infrastructure, though it recognised the need for a more sophisticated methodology to be implemented to raise planning efficiency and to improve the quality of planning results.

Research on new requirements for transport infrastructure planning can also be found in the aviation sector. Here, the 2050AP project explored novel solutions and new airport concepts for 2050 and beyond that are likely to mitigate the environmental impacts of airport activities and, crucially, improve interconnectivity with other transport modes.

A methodological contribution to the planning of airports is offered by the Italian study [Guidelines for planning of the Italian regional airports development](#) (2004-2006) that, in particular, provided an understanding of the most suitable procedural framework for developing regional airports. The results of this project were the definition and monitoring of planning policies to prioritise investments on regional airports, given the amount of public financial resources that are available.



A perspective on infrastructure planning was explored in cross-border projects that aimed to develop a common approach for transport infrastructure and the better integration of transport networks.

This applies, for example, to the MEDA TEN-T project, which designed a strategy for achieving integrated infrastructure planning, interconnectivity and interoperability of transport systems in the Mediterranean region, and between the EU and the Mediterranean countries. Among its results, the MEDA TEN-T project developed a strategic master plan, which is intended to be a systematic procedural framework for readjusting transport policies by the EU and the Mediterranean countries.

The SEB-TRANS-LINK project assessed the requirements for the development of the South East Baltic Transport corridor. It stressed the need for an improved transport infrastructure planning process to prioritise investments to achieve sufficient accessibility, security and environmental sustainability.

### 4.1.3 Research outcomes

#### 4.1.3.1 Achievements of the research under this sub-theme

Research in transport infrastructure planning has heavily contributed to shaping European and national transport policies over the past decades. An outstanding example of this contribution is the evidence that the demands put on transport infrastructure planning, from the perspectives of land use and environmental planning, have considerably evolved since the original thinking – not least because of the increasing focus on long-term goals for greater sustainability of the transport systems.

Elsewhere, the planning process has become more inclusive and participatory as it has increasingly involved all relevant stakeholders, whose awareness around planning issues has progressively matured. This has not only encouraged the design of alternatives with a view to providing a higher social value, but has also facilitated a more holistic planning process that now considers potential conflicts and underlying complementarities when a transport infrastructure is designed and planned. On the whole, a planning process that is more comprehensive and integrated means it is less likely that the external effects of transport infrastructure will be overlooked, while taking the opportunity to control them through targeted interventions.

#### 4.1.3.2 Transferability from research to practical use

The findings from the research on this sub-theme have certainly accrued and improved, and the consequent wealth of knowledge and information is now increasingly becoming available to decision makers, researchers and industry. Over time, stakeholders have benefited from operational concepts that are intended to give guidance to the planning and decision making involved in future developments. This has, in turn, enhanced evaluation and planning methodologies, not only at the level of implementing co-modality in large infrastructure, but also in the environment of urban mobility where cities are actively searching for planning policy lessons.

#### 4.1.3.3 Indications for future research

To reflect current critical challenges and opportunities in the area of transport infrastructure planning, a number of requirements have been identified that future research may address over the coming years.

Efforts will continue to create a common understanding and awareness around new and more sustainable planning concepts and practices at all levels of government – local, regional and national. This will involve a better knowledge of the barriers to transferability of the most effective practices, while encouraging the harmonisation of national land use and transport planning with the policy frameworks in EU Member States.

Research will also have to consider social trends and people's perceptions and preferences. This implies a better identification and understanding of those factors that exert influence on users' behaviour, and gaining more understanding of major social trends that impact on the demand for land and transport services.

#### 4.1.3.4 Implications for future policy development

EU-funded and national research have been key factors and have considerably contributed to improving the planning-related issues of the transport system across EU Member States. This has occurred because research has delivered new concepts and solutions (either methodological or technological) for sound decision making that have supported policy makers in developing and implementing comprehensive planning strategies.

However, despite this progress, the research projects analysed within this sub-theme indicate that a number of issues remain and for which further policy development is required in the future.

Within a wider context, future policy developments should look at a greater integration of the various policy instruments on land use and transport planning to which research has contributed a greater understanding. However, this integrated policy making should consider the diversity of the transport patterns across Member States. Therefore, future policy developments should be informed through a greater understanding of the transferability of results from one context to another to find integrated and tailored solutions for transport and land use planning.

In this respect, future policy developments should target better interfaces between the EU and its neighbouring countries, with a view to optimising corridors and traffic flows (passenger and freight) beyond the borders of the EU.

### 4.1.4 List of projects

Table 4-1 lists the more significant projects included in the review of this sub-theme.



Table 4-1 Projects reviewed in the planning sub-theme

Project acronym	Project name	Project duration	Source of funding
COST 332	Transport and Land-Use Policies <a href="https://goo.gl/jORyFd">https://goo.gl/jORyFd</a>	1996-2000	EU (COST)
COST 340	Towards a European intermodal transport network: lessons from History <a href="https://goo.gl/fQnT2H">https://goo.gl/fQnT2H</a>	2002-2004	EU (COST)
TRANSPLUS	TRANSPort Planning, Land Use and Sustainability <a href="https://goo.gl/vxTPFM">https://goo.gl/vxTPFM</a>	2000-2003	EU (FP5)
ERTRAC	European Road Transport 2020: a Vision and Strategic Research Agenda <a href="https://goo.gl/wbVVAR">https://goo.gl/wbVVAR</a>	2003-2006	EU (FP6-SUSTDEV)
ERTRAC II	Technology Platform for European Road Transport Research <a href="https://goo.gl/LbHakR">https://goo.gl/LbHakR</a>	2006-2009	EU (FP6-SUSTDEV)
FOSTER-ROAD	Future of Surface Road Transport European Research <a href="https://goo.gl/yyfclp">https://goo.gl/yyfclp</a>	2013-2016	EU (FP7-TPT)
LivingRAIL	Living in a sustainable world focused on electrified rail <a href="https://goo.gl/P4phUa">https://goo.gl/P4phUa</a>	2012-2015	EU (FP7-TPT)
TREND	Towards new Rail freight quality and concepts in the European Network in respect to market Demand <a href="https://goo.gl/S63znK">https://goo.gl/S63znK</a>	2005-2006	EU (FP7-TPT)
2050AP	The 2050+ Airport <a href="https://goo.gl/HwaK8I">https://goo.gl/HwaK8I</a>	2011-2014	EU (FP7-TPT)
MEDA TEN-T	Mediterranean and Trans-European Networks for Transport <a href="https://goo.gl/CSHnJw">https://goo.gl/CSHnJw</a>	2003-2005	EU (FP5)
SEB-TRANS-LINK	South East Baltic TRANSPort LINK <a href="https://goo.gl/59MNnu">https://goo.gl/59MNnu</a>	2002-2005	EU (INTERREG)
SPIDER PLUS	Sustainable Plan for Integrated Development through the European Rail Network Projecting Logistics & Mobility for Urban Spatial Design Evolution <a href="https://goo.gl/5Pn00k">https://goo.gl/5Pn00k</a>	2012-2015	EU (FP7-TPT)
N/A	Landscape fragmentation by transportation infrastructure in Switzerland: Quantitative analysis 1900-2002 and implications for traffic planning and regional planning <a href="https://goo.gl/884HqP">https://goo.gl/884HqP</a>	2005-2007	Switzerland
N/A	Influences of transport infrastructure on morphology and fragmentation of the landscape <a href="https://goo.gl/MD9qUK">https://goo.gl/MD9qUK</a>	2004-2008	Czech Republic
N/A	Ex-post analysis of the spatial impact of transport infrastructure – Case study of Zurich S-Bahn <a href="https://goo.gl/WXZ3cd">https://goo.gl/WXZ3cd</a>	2003-2004	Switzerland
N/A	Guidelines for planning of the Italian regional airports development <a href="https://goo.gl/BXz7ZO">https://goo.gl/BXz7ZO</a>	2004-2006	Italy

## 4.2 Assessment

### 4.2.1 Introduction to the sub-theme

The assessment (or appraisal) is a key step in assisting the process of planning transport systems and evaluating or forecasting the impacts of policy strategies. Transport infrastructure, as a core component of every transport system, is a key object of assessment methodologies aimed at supporting decision making and the policy dimensions.

The types of decision supported by the ex-ante evaluation include:

- prioritising projects within a programme;
- choosing between alternative solutions;
- deciding whether or not particular projects represent good social value for money;
- choosing the optimal time(s) to undertake an investment.

The assessment can also be performed after the realisation of the infrastructure (ex-post) to derive lessons learned to enhance future policy and projects. Ex-post evaluation provides evidence on how to identify the types of projects that work best in certain situations, the side effects of simultaneous investments in other sectors and their interaction with transport investments, and the time frame in which economic impacts materialise. Therefore, ex-post evaluation helps to set realistic expectations for the effect of investments and economic development, and it provides a fundamental contribution to improving ex-ante analyses.

There are two principal approaches to a project appraisal. The first is cost-benefit analysis (CBA). The basic principle of CBA is to maximise the net socio-economic benefit of the project, with an underlying assumption that social decisions can be founded on the aggregation of individuals' willingness to pay. An alternative approach to appraisal is multi-criteria analysis (MCA). The goal of MCA is to optimise a set of socially based objectives.

Over the last 20 years, the policy background for evaluating transport infrastructure has changed rapidly, with an increased complexity of the appraisal process. These changes fuelled relevant methodological developments concerning CBA:

- A growing trend towards multimodality has led to the search for appraisal frameworks that cover several modes simultaneously.
- The increased attention to environmental issues has led to a rapid expansion of the research on environmental sustainability (including cost assessments of air pollution, noise and global warming). Other research developments responded to an increasing demand for the reflection of social and regional impacts in evaluation by developing linkages between the transport sector, and the wider economy and competitiveness.

In addition to those aspects already highlighted in the 'planning' sub-theme, infrastructure assessment methodologies and tools have been developed by a number of projects where the main focus has been on management and, especially, maintenance issues. The inclusion of a life-cycle perspective into proper asset management strategies requires appropriate performance indicators to be monitored continuously to predict the need for infrastructure replacement.

#### 4.2.1.1 Overall direction of European-funded research

Since the 4th Framework Programme for Research and Technological Development (FP4) (1994-1998), research activities have addressed project and policy appraisals (e.g. the [FUNET-SASI](#) (1996-1999), [EUROSIL](#) (1997-1999) and [MAESTRO](#) (1998-1999) projects). However, it is with later framework programmes that major evaluation issues have been addressed (e.g. in the [IASON](#) (2001-2003) and [HEATCO](#) (20014-2006) projects), complemented by other activities not funded within research programmes (e.g. the [RAILPAG](#) (2004-2005) project), which was funded by the European Investment Bank (EIB) and the European Commission).

Given the high demand on public resources placed by transport infrastructure investments, great emphasis was put on:

- the methodological correctness of the appraisal process and the definition of monetary values to be used in economic analysis;
- the evaluation of the costs and benefits from a transport perspective (such as savings in travel time) and of wider socio-economic impacts of infrastructure projects (such as production, employment and environmental impacts).

Approaches for calculation methods and default values of external costs have been explored by the [IMPACT](#) (2008) project (a project that was not funded by the research programmes) and reported in the 'Handbook on External Costs of Transport' (2008), which has subsequently been updated.

EU research has also tried to fill the gap between ex-ante and ex-post evaluations, working on a better integration of the two assessment perspectives and thus improving methods analysing in detail the outcomes of past decisions (e.g. the [EVA-TREN](#) (2006-2008) project).

A number of forecasting tools at a European scale have been developed to predict expected passenger and freight transport demand and, consequently, the expected infrastructure bottlenecks and missing links. These tools are needed to facilitate the setting of priorities in the development of the Trans-European Networks and the elaboration of other elements of the Common Transport Policy (e.g. the [TRANSTOOLS](#) (2004-2006), [WORLDNET](#) (2007-2009) and [TRANSTOOLS 3](#) (2011-2014) projects). These projects complement the strategic policy assessment methodologies by evaluating the impacts of corridors and large infrastructure projects (e.g. the [CODE-TEN](#) (1998-1999) project).

In parallel, and with the aim of supporting the development of EU-scale transport modelling tools as a basis for transport planning and policy formulation, a European Transport Policy Information System was implemented progressively within the different Framework Programmes (e.g. the [ASSEMBLING](#) (1997–2000), [INFOSTAT](#) (1996–1997), [MESUDEMO](#) (1997–2000), [ETIS-BASE](#) (2002–2005), [ETIS-LINK](#) (2002–2005), [ETIS-AGENT](#) (2002–2006) and [ETISPLUS](#) (2009–2012) projects). The absence of relevant data and a complete and updated set of information for allowing proper infrastructure assessment was identified during FP4 by a number of transport assessment projects (e.g. the EUNET-SASI and [MEDA TEN-T](#) (2003–2005) projects).

#### 4.2.1.2 Overall direction of nationally funded projects

National research projects have contributed to the development of guidelines and tools for evaluating or predicting the impacts of infrastructure investments. The main examples include:

- ‘[Transport Analysis Guidance \(TAG\)](#)’, (Department for Transport, 1999) and ‘[Transport and the Economy](#)’, (SACTRA<sup>19</sup>, 1999) in the United Kingdom;
- ‘[L’évaluation socioéconomique des investissements publics](#)’, Commissariat général à la stratégie et à la prospective (CGSP, 2013) in France;
- ‘[Guide on economic evaluation of transport projects](#)’, (CEDEX<sup>20</sup>, 2010) in Spain;
- ‘[Evaluation of infrastructural projects – Guide for cost-benefit analysis](#)’, (Ministry of Transport, Public Works and Water Management and Ministry of Economic Affairs, 2000) in the Netherlands.

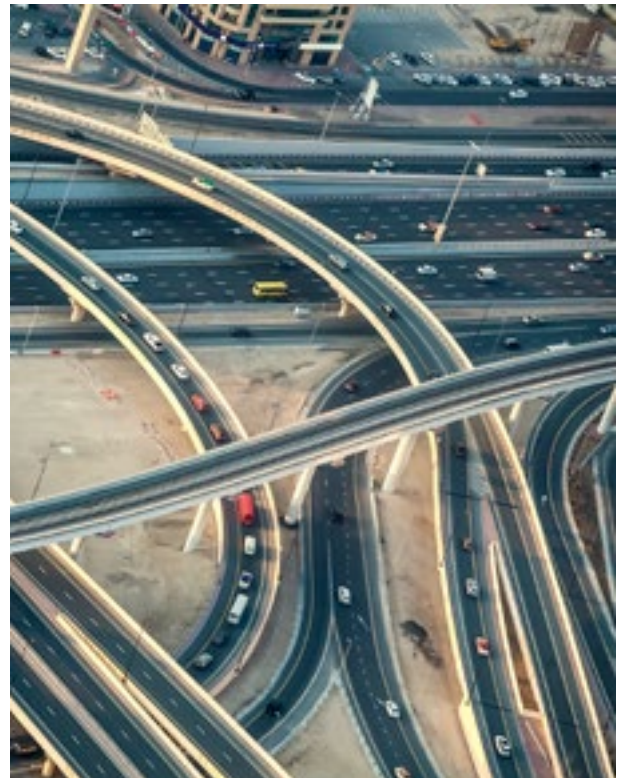
### 4.2.2 Research activities

#### 4.2.2.1 Appraisal methodologies

Research under this topic has developed methods and guidelines for assessing transport infrastructure investments and policy initiatives, including the effects on the wider economy and competitiveness.

The aim of the EUNET-SASI project was to develop a preferred approach to assessment and then to translate this preferred method into operational software. It was used to test the assessment of the Trans-Pennine corridor in the UK and long-distance freight movements in Finland. The overall approach to assessment that was adopted includes CBA and MCA analyses.

In parallel, the EUROSIL project developed an evaluation framework and software tool to support a structured approach to the assessment of the effects of regional developments. More specifically, the overall aim of EUROSIL was the development of reliable and comprehensive guidelines to support decision-making processes regarding the impacts of interconnectivity and interoperability of the Trans-European and Pan-European Networks.



The MAESTRO project developed, tested and documented a set of guidelines covering the various decisions and evaluation phases through the entire life-cycle of a project, from the definition of the transport problem, through project design and initial evaluation to implementation, final evaluation and exploitation of the results.

The IASON project focused on project appraisal at the EU level with an emphasis on regional/spatial economic impacts. The aims of IASON were to:

- improve existing assessment frameworks by ensuring that direct and indirect impacts are clearly distinguished, and that the incidence of benefits, costs and sources of additionality, and/or double counting are transparent;
- perform a systematic and quantitative analysis of the network, spatial and socio-economic impacts of transport investments and policy by refining existing EU-level models and carrying out scenario simulations;
- provide recommendations for the inclusion of indirect impacts in CBA and the development of supporting tools and databases.

At an urban level, the [TRANSECON](#) (2001–2003) project demonstrated third-party effects of large-scale urban public transport infrastructure investments. These included the stimulation of socio-economic development in areas of improved accessibility, the stimulation of re-urbanisation dependent on the potential development, the potential of decentralising housing (spatial diffusion) and the centralisation of shopping.

<sup>19</sup> Standing Advisory Committee on Trunk Road Assessment.

<sup>20</sup> Centro de Estudios y Experimentación de Obras Públicas.

The primary objective of the HEATCO project was to develop harmonised guidelines for project assessment and transport costing at an EU level. These guidelines were based on welfare economics and CBA. HEATCO identified the elements of a consistent framework for project appraisal at the EU level based on:

- general issues (including non-market valuation techniques, benefit transfer, treatment of non-monetised impacts, discounting and intra-generational equity issues, decision criteria, the project appraisal evaluation period, treatment of future risk and uncertainty, the marginal costs of public funds, producer surplus of transport providers and the treatment of indirect socio-economic effects);
- value of time and congestion (including the treatment of congestion, unexpected delays and reliability);
- value of changes in accident risks;
- environmental costs (air pollution, noise and climate change);
- costs and indirect impacts of infrastructure investment.

When considering the balance between ex-ante and ex-post evaluation, the EVA TREN project improved the ex-ante practices for assessing large energy and transport infrastructure projects through the ex-post analysis of several case studies. The comparison between results of ex-ante and ex-post analyses for different case studies identified several possible improvements to the traditional ex-ante evaluation procedures to provide more reliable evaluations of infrastructure projects. A new assessment procedure was also defined, taking into account the whole project life, from initial appraisal to ex-post evaluation. This second result provided more details on the often-neglected aspects of economic evaluation.

Other projects that were not funded by research programmes also contributed to setting the scene of appraisal methodologies. Examples include the RAILPAG and IMPACT projects.

The RAILPAG project aimed to provide a common framework for the appraisal of railway projects across the EU. The guidelines were prepared following an initiative of the EIB with the support of the European Commission, international financial institutions and key associations of the rail industry. The RAILPAG report was intended to be the first step towards a comprehensive harmonised methodology for appraising rail investments in the EU.

The central aims of the IMPACT study (2008) were to support the European Commission in carrying out impact assessments of strategies to internalise transport external costs and to provide a comprehensive overview of approaches for calculating external costs. This resulted in the publication of the 'Handbook on External Costs of Transport' (2008), which provided a set of default values covering all environmental, accident and congestion costs for all transport modes. The handbook proved to be an important source of input data and unit cost values for policy analysis, research projects and academic papers in Europe. To maintain this strong standing, the handbook was further updated in 2014 in the context of a study commissioned by the European Commission's Directorate-General for Mobility and Transport (DG-MOVE).

Looking at national research projects, the 'Transport and the Economy' study showed that, if imperfections in the economy exist, the value of initial 'transport' impacts will not be the same as the value of final 'economic' impacts. In that case, the conventional appraisal method would still leave out some wider economic impacts.





The TAG project is a comprehensive study of transport benefits and costs, and a guidebook for applying this information. It is one of the most comprehensive studies of its kind, including many often-overlooked impacts.

The 'L'évaluation socioéconomique des investissements publics' report updated and enriched the socio-economic evaluation methodology of public investment, studied the conditions for good appropriation of its results by policymakers and extended the socio-economic calculation beyond its traditional application areas (such as transport and energy).

The 'Guide on economic evaluation of transport projects' is the result of the research project entitled 'Socioeconomic and financial evaluation of transport projects' funded by the Centro de Estudios y Experimentación de Obras Públicas (CEDEX) of the Spanish Ministerio de Fomento.

On the initiative of the Dutch Ministry of Transport, Public Works and Water Management, and the Dutch Ministry of Economic Affairs, a large-scale research programme entitled 'Economic Effects of Infrastructure' (OEEI) was carried out. The results of OEEI were published in a guide and eight underlying reports. The guide makes an inventory of internationally prescribed evaluation methods to extract lessons to improve Dutch practice, describing a broad range of effects and methods to determine them.

#### 4.2.2.2 Assessment of impacts

A number of research projects focused on strategic assessment of infrastructure corridors and networks.

The CODE-TEN project developed a strategic policy assessment methodology (DECODE) for evaluating the impacts of the development of pan-European corridors. Using the methodology, alternative corridors were assessed against three aspects – socio-economic development, policy development and infrastructure planning. This provided a tool to prioritise infrastructure investments.

The TRANSTOOLS, WORLDNET and TRANSTOOLS 3 projects focused on developing a European transport network model covering all modes (road, rail, inland waterways, maritime and air transport), and freight and passenger transport. Developed by combining existing models into one new model, the tool was intended to provide the European Commission with an in-house instrument of simulation for assessing EU transport policy and to facilitate priority setting in the development of the TEN-T and the elaboration of other elements of the Common Transport Policy.

Methods for determining the socio-economic impacts, such as employment and economic growth of transport infrastructure investments, have been analysed by the [ECOPAC](#) (1996-1998) project. This addressed the effect on employment due to increased investment by other sectors of the economy in the vicinity of new transport infrastructure.

More recently, and in parallel with the ongoing economic crisis, the [I-C-EU](#) (2012-2014) project investigated the relationship between transport infrastructure investment and its wider economic impacts – in particular, competitiveness and economic growth. Starting from a sound analysis of assessment tools used to evaluate transport infrastructure, the project generated

a modified methodological framework for policy intervention and recommendations. This framework was then tested on a representative sample of current transport projects to analyse economic growth and competitiveness. Indicators for use at national and regional level, measuring direct and indirect effects of transport infrastructure investment, have been developed.

In addition, the [BENEFIT](#) (2014-2016) project provided a methodology for assessing transport infrastructure provision, operation and maintenance according to proper funding and financing schemes, and the influence that external factors and the context of the transport mode might have on the business model. Success in relation to the application of a particular business model is seen as an assessment of the appropriate matching of elements. The framework allows for the transferability of findings with respect to lessons learned, limitations, and the impact of the financial and economic crisis.

Research has also addressed the development of harmonised methodologies and procedures at the European level to evaluate and monitor the environmental impact of transport infrastructure and its inclusion into the broader socio-economic assessment.

To ensure that the full environmental impacts of the TEN-T are assessed, and not just the impacts of individual sections of infrastructure, the guidelines for the development of the TEN-T required the development of methods for strategic environmental assessments (SEA) of the network and individual corridors (Decision 1692/96/EC).

In this respect, the [INTERNAT](#) (1999) project defined priority research areas with the principal aim of establishing an integrated tool for SEA of European network and transport corridors. The INTERNAT project assessed the potential for new and improved analysis methods as part of an integrated tool for SEA covering a wide range of impacts, including evaluating the impact of transport infrastructure on the landscape, using indicators for land take and visual impacts, and integrating recent standards for life-cycle analysis (LCA) into SEA methods. The project developed prototype software for applying geographic information systems (GIS) into an SEA that is applicable at an EU network level and at regional and local corridor levels. The INTERNAT project highlighted the need for research to develop complex spatial models of biodiversity and the availability of more spatially detailed databases on land use.

In a similar manner, the [COMMUTE](#) (1996-1999) project defined a methodology and a software tool for conducting SEAs of the impacts of transport infrastructure. The tool is primarily applicable to policy decision-making at the European level and covers road, rail, air and waterborne transport modes. A pilot SEA performed in the context of the study provided an initial quantification of the impacts of TEN-T infrastructure and demonstrated the feasibility of the proposed methods.

Research carried out within the Conference of European Directors of Roads (CEDR) framework (former European Research Area Network (ERA-NET) and current CEDR calls) focused on road infrastructure assets and related management practices, and monitoring tools for long-term planning or anticipation of the timing and volume of investments.





The key performance indicators used to assess safety, reliability and value for money/economy of road networks – measuring mainly economic aspects – have been integrated with indicators designed to properly evaluate the environmental and social performance of transport infrastructure. This was achieved in particular by the [EVITA](#) (2010-2012) and [SBAKPI](#) (2010-2012) projects. A further step was made with the [LICCER](#) (2012-2013) project, which developed a model (including a framework and guidelines) based on existing tools and methodologies for LCA of road infrastructure, to be used in an environmental impact assessment (EIA) process in the early stage of transport planning.

The [HEROAD](#) (2011-2012) project specifically addressed a holistic evaluation of road assessments taking into account the combination of individual components, levels of assessment and the inclusion of a life-cycle perspective. It included new challenges such as climate change and new materials. The [MIRAVEC](#) (2011-2013) project applied the same holistic approach and considered a broad variety of effects (e.g. the interaction between road design and traffic flow), and the capabilities of available models and tools to evaluate the relative importance of different road infrastructure characteristics for different settings (e.g. topography or network type).

More recently, extreme weather phenomena and the impacts of climate change on national and European road networks have been analysed by making use of climate projections and specific impact models – in particular, to estimate the relevant parameters for road maintenance (e.g. the [CLIPDaR](#) (2013) project).

Tools and guidelines to facilitate the integration of noise abatement into planning and management situations of

national road administrations (NRAs) have been developed by the [ON-AIR](#) (2013-2015) project. It considered such integration in the whole chain from strategic planning, EIA and detailed project development to the management and maintenance of road infrastructure.

In the railway sector, the [INFRAGUIDER](#) (2009-2010) project defined the guidelines for developing an effective European method/tool for the EIA of the railway infrastructure (existing and new). The overall result is a combined view of railway infrastructure material flows, management and material procurement. This provided clear guidance towards improved environmental performance, on a global climate scale and on local and regional scales, including waste minimisation and reducing the level of toxic substances.

For this sub-theme, several national projects have been identified and analysed. Their presence is often linked to the need to assess a wide range of infrastructural projects, ranging from very focused ones (e.g. the Irish [Nenagh ByPass – Noise Aspects](#) (2000) project that evaluated the improvement in noise levels resulting from the opening of a highway bypass) to those that are more network or corridor based (e.g. assessing the alternatives for the [Development of transport networks in the Czech Republic](#) (2004-2006)). They often also involve the development of improvements to the appraisal methodologies.

In Switzerland, projects have focused on aspects such as macro-economic and spatial effects of new infrastructure (e.g. the [SPATIAL EFFECTS 2](#) (2003-2004) and [Ex-post analysis of the spatial impact of transport infrastructure – Case study of Zurich S-Bahn \(suburban rail\)](#) (2003-2004) case studies). Two further projects, [Benchmarking of the infrastructure costs](#) (2003)

and [Discount rate in cost benefit analysis for infrastructure projects in transportation](#) (2004-2006), developed approaches for estimating costs and econometric parameters that should be considered when evaluating public infrastructure projects. An interdisciplinary pilot study [NRP 54 – B7](#) (2006-2009) on the transalpine transportation corridors evaluated the optimal resilience for vulnerable infrastructure networks.

A study on the [Effects of infrastructure investments on the labour market](#) (2004) was carried out in Sweden, while another analysed the [Impacts of road maintenance on regional economy](#) (2008) in Finland.

To assist in identifying the required investments in rail infrastructure and equipment through the use of monitoring and simulation tools, the [SCRIPT](#) (2012-2015) project focused on the development of robust railway transport plans. It assessed the consequences of various disturbances on such plans and achieved a better understanding of the various indicators or metrics that can measure these consequences.

The ongoing [VEU](#) (2014-2017) project aims to build plausible, transparent and reproducible models of possible future mobility systems, and to conduct the analysis of the effects those systems would have, especially on the environment.

### 4.2.3 Research outcomes

#### 4.2.3.1 Achievements of the research under this sub-theme

Overall, EU and national research under this sub-theme progressed well in developing appraisal methods and tools. The strict linkage between policy background and evaluation pushed the development of new assessment methods.

With respect to economic appraisal, the results of the research have enabled the monetary values of external effects to be defined, together with the creation of tighter linkages between transport models and economic appraisal. They have also contributed to the development of evaluation capabilities for multimodal systems. The research results have also enabled transport service provisions at a pan-European level to be investigated, and international traffic and transboundary impacts to be considered. However, the most significant developments have been in the appraisal of wider impacts of transport infrastructure on the economy.

Reliable simulation models at the European scale have been developed to predict expected transport demand. This enables the impacts of new investments to be evaluated.

Research showed that, although large infrastructure projects are executed in very different contexts, the identified best practices exhibit large similarities. This makes the development of comparison and assessment tools highly beneficial.

#### 4.2.3.2 Transferability from research to practical use

The transferability from research to practical use is particularly evident in the case of infrastructure assessment since appraisal methods and tools are generally developed on ex-post and ex-ante analyses of real case studies.

At a European level in particular, research projects are highly interlinked. New projects build on the results of predecessors, while a simultaneous evolution of transport models and of the European Transport Policy Information System contributed to the definition of a more complete and validated framework of assessment methodologies.

#### 4.2.3.3 Indications for future research

Despite these advancements and broad scope, progress is still required in appraisal methods and tools.

The recent economic crisis has accentuated the importance of gaining a deeper understanding of the wider economy impacts. This clearly indicates that further research is needed to enhance the estimation of the wider economic effects (also through empirical research) and to define good practices.

Another important research topic concerns ex-post evaluation. European research on this issue is poor. Therefore, it is not possible to:

- improve the methodology of ex-ante evaluation by drawing lessons from the past;
- identify the causes of any discrepancies between expectations and actual results.

There is also the need to develop guidelines for collecting information required for the ex-post analysis during the ex-ante stage.

Linked to the previous point, another research need concerns improving risk analysis by deriving insights from ex-post evaluation. Risk analysis simulations use probability distributions that are generally based on assumptions by the analyst. In this way, the results of simulations are heavily dependent on these assumptions, thus reducing the reliability of the analysis. More research on ex-post analyses (classified by type of project, country, etc.) would contribute to the derivation of average probability distributions and to the standardisation of the key parameters of risk analyses.

Finally, further research might improve the methodology for prioritising public-private partnership (PPP) projects and those projects partially self-financed by revenues in the presence of budgetary constraints. Bonnafous and Jensen (2005) show that, in such cases, the optimal ranking is not necessarily the ranking of decreasing socioeconomic internal rate of return (IRR). The topic requires further study and it would be useful to test its practical implications.

#### 4.2.3.4 Implications for future policy development

Policy should continue to support the development and application of appraisal methods to infrastructure investments. In particular, the synchronisation of projects' scope, development and evaluation should be guaranteed to avoid subsequent changes in a project (sometimes after decision makers have approved it) proceeding without any assessment of the incremental costs and benefits or of the wider impacts on the economy and/or environment.

#### 4.2.4 List of projects

Table 4-2 lists the more significant projects included in the review of this sub-theme.

Table 4-2 Projects reviewed in the assessment sub-theme

Project acronym	Project name	Project duration	Source of funding
ASSEMBLING	Assembling a European Network of Monitoring Centres for Transport Infrastructure <a href="https://goo.gl/xz2My1">https://goo.gl/xz2My1</a>	1997-2000	EU (FP4)
BENEFIT	Business Models for Enhancing Funding and Enabling Financing of Infrastructure in Transport <a href="https://goo.gl/QxpVWx">https://goo.gl/QxpVWx</a>	2014-2016	EU (IEE)
CODE-TEN	Strategic Assessment of Corridor Developments, TEN Improvements and Extensions to the CEEC/CIS <a href="https://goo.gl/Vz6M70">https://goo.gl/Vz6M70</a>	1998-1999	EU (FP4)
COMMUTE	Common Methodology for Multi-Modal Transport Environmental Impact Assessment <a href="https://goo.gl/fKfFH4">https://goo.gl/fKfFH4</a>	1996-1999	EU (FP4)
ECOPAC	Econometrics of Impacts <a href="https://goo.gl/mu00Az">https://goo.gl/mu00Az</a>	1996-1998	EU (FP4)
ETIS-AGENT	European Transport Information System Agent <a href="https://goo.gl/c0kHT6">https://goo.gl/c0kHT6</a>	2002-2006	EU (FP5-GROWTH)
ETIS-BASE	Core Database Development for the European Transport policy Information System (ETIS) <a href="https://goo.gl/E6Cjvx">https://goo.gl/E6Cjvx</a>	2002-2005	EU (FP5-GROWTH)
ETIS-LINK	Thematic Network for European Transport policy Information System Development <a href="https://goo.gl/NR6Y2v">https://goo.gl/NR6Y2v</a>	2002-2005	EU (FP5-GROWTH)
ETISPLUS	European Transport Policy Information System Development and Implementation of Data Collection Methodology for EU Transport Modelling <a href="https://goo.gl/ymJUOq">https://goo.gl/ymJUOq</a>	2009-2012	EU (FP7-TPT)
EUNET-SASI	Socio-Economic and Spatial Impacts of Transport <a href="https://goo.gl/J84V25">https://goo.gl/J84V25</a>	1996-1999	EU (FP4)
EUROSIL	European Strategic Intermodal Links <a href="https://goo.gl/1KFS4i">https://goo.gl/1KFS4i</a>	1997-1999	EU (FP4)
EVA-TREN	Improved decision-aid methods and tools to support evaluation of investment for transport and energy networks in Europe <a href="https://goo.gl/ypzNvX">https://goo.gl/ypzNvX</a>	2006-2008	EU (FP6-INTEGRATING)
HEATCO	Developing Harmonised European Approaches for Transport Costing and project assessment <a href="https://goo.gl/EqObQ2">https://goo.gl/EqObQ2</a>	2004-2006	EU (FP6-INTEGRATING)
IASON	Integrated Appraisal of Spatial economic and Network effects of transport investments and policies <a href="https://goo.gl/xUkchf">https://goo.gl/xUkchf</a>	2001-2003	EU (FP5-GROWTH)
I-C-EU	Impact of Transport Infrastructure on International Competitiveness of Europe <a href="https://goo.gl/uMx2IM">https://goo.gl/uMx2IM</a>	2012-2014	EU (FP7-TPT)
IMPACT	Internalisation Measures and Policies for All external Cost of Transport <a href="https://goo.gl/FvE41W">https://goo.gl/FvE41W</a>	2008	EU (FP5-GROWTH)

Table 4-2 (continued) Projects reviewed in the assessment sub-theme

Project acronym	Project name	Project duration	Source of funding
INFOSTAT	Information Systems <a href="https://goo.gl/eUGgtF">https://goo.gl/eUGgtF</a>	1996-1997	EU (FP4)
INFRAGUIDER	Infrastructure Guidelines for Environmental Railway Performance <a href="https://goo.gl/tFMpr3">https://goo.gl/tFMpr3</a>	2009-2010	EU (FP7-TPT)
INTERNAT	Integrated Trans European Network Assessment Techniques <a href="https://goo.gl/GYP2P9">https://goo.gl/GYP2P9</a>	1999	EU (FP4)
MAESTRO	Monitoring, Assessment and Evaluation of Transport Policy Options in Europe <a href="https://goo.gl/NYU3zs">https://goo.gl/NYU3zs</a>	1998-1999	EU (FP4)
MEDA TEN-T	Mediterranean and Trans-European Networks for Transport <a href="https://goo.gl/C5HnJw">https://goo.gl/C5HnJw</a>	2003-2005	EU (FP5)
MESUDEMO	Methodology for establishing a database on transport supply, demand and modelling in Europe <a href="https://goo.gl/j9QOEt">https://goo.gl/j9QOEt</a>	1997-2000	EU (FP4)
RAILPAG	Railway Project Appraisal Guideline <a href="https://goo.gl/B92NUQ">https://goo.gl/B92NUQ</a>	2004-2005	EU (EIB)
TRANSTOOLS	Tools for Transport Forecasting and Scenario Testing <a href="https://goo.gl/7LnYH2">https://goo.gl/7LnYH2</a>	2004-2006	EU (FP6-INTEGRATING)
TRANSTOOLS 3	Research and Development of the European Transport Network Model Transtools Version 3 <a href="https://goo.gl/86h1Fg">https://goo.gl/86h1Fg</a>	2011-2014	EU (FP7-TPT)
TRANSECON	Urban TRANSport and local Socio-ECONomic development <a href="https://goo.gl/aeHTFe">https://goo.gl/aeHTFe</a>	2001-2003	EU (FP5)
WORLDNET	European Transport Network Model Refinement Regarding Freight and Intermodal Transport to and from the Rest of the World <a href="https://goo.gl/h2jrCW">https://goo.gl/h2jrCW</a>	2007-2009	EU (FP6-INTEGRATING)
CLiPDaR	Design guideline for a transnational database of downscaled Climate Projection Data for Road impact models <a href="https://goo.gl/OofOpw">https://goo.gl/OofOpw</a>	2013	CEDR
EVITA	Environmental Indicators for the Total Road Infrastructure Assets <a href="https://goo.gl/XBoHXS">https://goo.gl/XBoHXS</a>	2010-2012	CEDR
HEROAD	Holistic Evaluation of Road Assessment <a href="https://goo.gl/pxkLse">https://goo.gl/pxkLse</a>	2011-2012	CEDR
LICCER	Life Cycle Considerations in EIA of Road Infrastructure <a href="https://goo.gl/wz3DOR">https://goo.gl/wz3DOR</a>	2012-2013	CEDR
MIRAVEC	Modelling Infrastructure influence of RoAd Vehicle Energy Consumption <a href="https://goo.gl/nCdWOS">https://goo.gl/nCdWOS</a>	2011-2013	CEDR
ON-AIR	Optimised Noise assessment and management guidance for National Roads <a href="https://goo.gl/gG02ly">https://goo.gl/gG02ly</a>	2013 -2015	CEDR
SBAKPI	Strategic Benchmarking and Key Performance Indicators <a href="https://goo.gl/GsUkbr">https://goo.gl/GsUkbr</a>	2010-2012	CEDR
TAG	Transport Analysis Guidance <a href="https://goo.gl/IHJoSn">https://goo.gl/IHJoSn</a>	1999	United Kingdom

Table 4-2 (continued) Projects reviewed in the assessment sub-theme

Project acronym	Project name	Project duration	Source of funding
N/A	Transport and the Economy <a href="https://goo.gl/H2hwGN">https://goo.gl/H2hwGN</a>	1999	United Kingdom
N/A	L'évaluation socioéconomique des investissements <a href="https://goo.gl/RsYFTN">https://goo.gl/RsYFTN</a>	2013	France
N/A	Guide on economic evaluation of transport projects <a href="https://goo.gl/VSXNw5">https://goo.gl/VSXNw5</a>	2010	Spain
N/A	Evaluation of infrastructural projects – Guide for cost-benefit analysis <a href="https://goo.gl/2cpfUy">https://goo.gl/2cpfUy</a>	2000	Netherlands
N/A	Nenagh ByPass – Noise Aspects <a href="https://goo.gl/3teKtW">https://goo.gl/3teKtW</a>	2000	Ireland
N/A	Development of transport networks in the Czech Republic until 2010 with an outlook towards 2015 <a href="https://goo.gl/YnGUJO">https://goo.gl/YnGUJO</a>	2004-2006	Czech Republic
SPATIAL EFFECTS 2	Spatial Effects of the transport infrastructure in the Magadino Plain <a href="https://goo.gl/pOqVEW">https://goo.gl/pOqVEW</a>	2003-2004	Switzerland
N/A	Ex-post analysis of the spatial impact of transport infrastructure – Case study of Zurich S-Bahn (suburban rail) <a href="https://goo.gl/WXZ3cd">https://goo.gl/WXZ3cd</a>	2003-2004	Switzerland
N/A	Swiss benchmarking of infrastructure costs (78 000 103 440) <a href="https://goo.gl/101PLv">https://goo.gl/101PLv</a>	2003	Switzerland
N/A	Discount rate in Cost Benefit Analysis for Infrastructure projects in Transportation (VSS2003/201) <a href="https://goo.gl/A80yKd">https://goo.gl/A80yKd</a>	2004-2006	Switzerland
NRP 54 – B7	Evaluation of the optimal resilience for vulnerable infrastructure networks – an interdisciplinary pilot study on the transalpine transportation corridors <a href="https://goo.gl/ZdOmyv">https://goo.gl/ZdOmyv</a>	2006-2009	Switzerland
N/A	Effects of infrastructure investments on the labour market <a href="https://goo.gl/y1q1Pb">https://goo.gl/y1q1Pb</a>	2004	Sweden
N/A	The impacts of road maintenance on regional economy <a href="https://goo.gl/nfBJ7W">https://goo.gl/nfBJ7W</a>	2008	Finland
SCRIPT	Decision Support System for Robust Design and Service Quality Indicators of Railway Transport Plans <a href="https://goo.gl/lRY2CB">https://goo.gl/lRY2CB</a>	2012-2015	France
VEU	Transport and the Environment <a href="https://goo.gl/JJioa7">https://goo.gl/JJioa7</a>	2014-2017	Germany

## 4.3 Pricing, funding and financing

### 4.3.1 Introduction to the sub-theme

Investment in transport infrastructure is irreversible in nature and poses particular challenges that are not found in other areas of public procurement. The fundamental reason is that infrastructure is a highly complex subject requiring economic, political, social and environmental considerations, and has a long time frame. Governments have to make a series of decisions to deliver transport infrastructure to citizens or taxpayers. At each stage, there are several important economic theories that could guide that decision making.

The pricing of the use of transport infrastructure can contribute decisively to increasing the efficiency of transport systems, by:

- generating welfare gains through the optimal use of capacity;

- orienting travel demand towards choices (of mode, time of travel, etc.) in a way that reduces the costs imposed on society as a whole;
- mobilising the financial resources required to develop transport infrastructure and services.

Key in this context is the principle of social marginal cost (SMC) pricing, which implies that each user of transport infrastructure should pay for the full marginal social cost imposed by that infrastructure use. The principle is valid in situations with competitive markets and without monopolies, and where fixed costs are small (sometimes referred to as 'first best'). When these conditions are not fulfilled, economic theory provides indications on the corrections to apply to the pure and strict SMC principles.



These principles have fuelled a lot of research aimed at developing workable and common methodologies to implement pricing instruments that would be efficient in different contexts and which are based on the most appropriate price levels.

A funding scheme is considered to be any combination of private and public income generated by or towards the infrastructure over its life-cycle. These may include user contributions (tolls, fees, fares, etc.) or public contributions. Therefore, the themes of pricing and funding are closely intertwined, the first being an element of the second. A financing scheme is considered to be any combination of public and/or private financial investments required by the infrastructure over its life-cycle. Research has focused on analysing the impacts of funding schemes and on the relationship between the funding and financing of transport infrastructure. Over the last 30 years, different means of transport infrastructure financing have been exploited including private financing initiatives and PPPs. Private sector participation in infrastructure investment has gained popularity in recent times because of the scarcity of resources in the public sector and because of the ability of the private sector to build, operate and maintain such facilities. The private sector is also able to take on a share of the risks and future uncertainties. However, despite the usefulness of PPP procurement of transport infrastructure, the success rate of PPP projects is still below expectations. This situation is explained to a large extent by the complexity of PPP models. This complexity is determined by the difficulty of choosing the optimal mix of public and private financing, and by the need to manage a broad range of unconventional financial instruments that are used in such models.

Therefore, research in the field of financing and funding of transport infrastructure is key to the development of novel approaches for generating successful investment portfolios and supporting current ones.

#### 4.3.1.1 Overall direction of European-funded research

Over the past two decades, a large number of research projects have been developed within the various FPs.

During FP4, considerable efforts were devoted to research on the development of methodologies and tools to support the assessment of the impacts of SMC pricing on transport infrastructure use (e.g. the [TRENEN II STRAN](#) (1996-1998), [PETS](#) (1996-1999), [TRANSPRICE](#) (1996-1998) and [EUROTOLL](#) (1996-1999) projects).

In later years, with the subsequent FPs, research moved on to wider topics, such as:

- analysing methodological and practical issues associated with implementing pricing policies including the estimation of costs (e.g. the [RECORDIT](#) (2000-2002), [UNITE](#) (2000-2003) and [CATRIN](#) (2005-2009) projects);
- identifying policy packages and the assessment of phased approaches favouring the introduction of pricing reforms (e.g. the [MC-ICAM](#) (2001-2003) project);

- appraising acceptability barriers (e.g. the [PATS](#) (1999-2000) and [DIFFERENT](#) (2006-2008) projects);
- identifying optimal approaches to revenue use (e.g. the [REVENUE](#) (2003-2005) project);
- analysing the problems of the current funding framework for large European transport infrastructure (e.g. the [FUNDING](#) (2005-2008) project);
- determining the main challenges of the implementation of SMC pricing within PPP (e.g. the [ENACT](#) (2007-2009) project).

Research on financing infrastructure projects focused on:

- developing adequate and realistic financing schemes for Trans-European Transport (TEN) infrastructure projects (e.g. the [INFRAFIN](#) (1997-1998) and [PROFIT](#) (1999-2000) projects);
- determining the appropriate choice of financing schemes (e.g. the [FISCUS](#) (1998-1999) project);
- identifying the critical success factors of financing schemes for investments in infrastructure (e.g. the [TUD COST Action TU1001](#) and [BENEFIT](#) (2014-2016) projects).

#### 4.3.1.2 Overall direction of nationally funded projects

Few studies seem to be available at a national level and the content of those that are is very heterogeneous.

#### 4.3.2 Research activities

EU-funded research on the pricing and financing of transport infrastructure covers a wide variety of projects.

##### 4.3.2.1 Pricing and funding

EU-funded research on the pricing and funding of transport infrastructure addressed optimal pricing policies, their relationship with infrastructure investment and operational strategies, their impact on society and ways to increase their public acceptability.

The TRENEN II STRAN project focused on the development of strategic models for assessing pricing reform in transport and their applicability to the EU. The strategic models were designed to examine the extent to which existing prices differed from marginal social costs, and to look at the consequences for traffic and modal split of moving to marginal social cost pricing. In addition, the models examined a range of intermediate pricing reforms. The models were used in five urban case studies and in two interregional case studies. The main contribution of using highly simplified models was to advance a consistent direction of reform.

A comprehensive review of the theory, current practice and pricing trends, and empirical estimates of appropriate price components was conducted in the PETS project. Five case studies, covering a variety of contexts, were carried out to determine the appropriateness of existing prices and the impact of moving to prices that better reflect external costs.



The pricing policy implications were also established. Pricing principles were explored to establish a common methodology for making transport pricing decisions. The starting point of the PETS analysis was that social surplus is maximised when price is set equal to the SMC. Cost recovery was considered as a secondary objective.

The TRANSPRICE project examined trans-modal pricing options by means of case studies involving modelling and demonstration projects. It aimed to address the issues of integrated trans-modal transport pricing; to achieve the optimum modal split in urban areas; and to allow for revenue allocation from road user charges to be used to finance investment in public transport, non-motorised modes, road safety and environmental improvements.

The impacts of actual pricing innovations were examined in the EUROTOLL project. The aim was to assess road pricing and tolling mechanisms, including the use of tolls as a financial leverage tool. It presented a review of transport demand management (TDM) strategies, including:

- their design and implementation in case studies;
- analysing the conditions for obtaining efficiency and the expected demand reactions with regard to TDM strategies;
- the effects of integrating information and pricing in TDM;
- the policy issues of tolling strategies regarding the reduction of external effects, congestion management, user acceptance and social acceptability.

Pilot projects focusing on road charging and interoperability have also been funded (e.g. the [RCI](#) (2005–2008) project). The RCI project developed an open, integrated framework enabling road charging interoperability at the technical (and related procedural) level, based on the key existing and planned road charging deployments in Europe.

Public and political acceptance is a key problem for the implementation of pricing innovations. The PATS project dealt with this issue, analysing the distributional effects of pricing, designing acceptable pricing schemes and policy packages, and identifying the legal and political barriers to the implementation of pricing schemes.

The MC-ICAM project addressed issues related to the actual implementation of the pricing principle. It investigated an implementation path of change. MC-ICAM specifically addressed the following themes:

- criteria for the implementation path;
- barriers and constraints to implementation;
- the welfare impacts of the implementation.

It proposed optimal and feasible implementation paths (applicable under different circumstances).

To identify the level of charges that would be necessary to meet the principle of user pays or marginal social cost pricing, it is necessary to identify in detail the structure of internal and external costs for the particular situation of interest. The RECORDIT project concentrated on the issue of real cost calculation, including internal and external elements. It defined and validated a methodology for calculating the real costs of intermodal freight transport, compared real costs to charges and taxes paid, and assessed current imbalances and market distortions.

The UNITE project described appropriate methodologies and empirical evidence for setting charges for transport infrastructure use. It demonstrated that a variety of methods are needed to estimate marginal social costs, applied together to overcome difficulties in the availability of appropriate data. A pragmatic approach, using a combination of cost allocation, econometric and engineering models was used, with the precise approach differing between cost categories.

The research was divided into two main sections: the development of transport accounts and case studies on marginal costs. A highly disaggregated system of information, with descriptions of marginal costs, fixed and variable transport costs, and related revenues per country was developed.

The objective of the [TIPMAC](#) (2001-2003) project was to combine transport modelling with macroeconomic modelling to study the indirect macroeconomic impacts of TEN-T transport infrastructure projects and transport pricing policies in the EU. It used the White Papers 'Fair Pricing for Infrastructure Use' and 'European Transport Policies for 2010: time to decide' as a starting point. Three common scenarios, all revenue neutral and including alternative options for the funding of TEN-T projects, which used offsets from reductions in personal income tax, were defined and analysed.

From research carried out in previous years it was found that the impact of pricing policies depends heavily (in terms of effectiveness, efficiency, equity and acceptability) on the use that will be made of the revenues generated by transport pricing schemes. The [REVENUE](#) project addressed this specific issue. Firstly, it provided a theoretical framework for integrating the efficient use of transport infrastructure in the short run and the efficient provision of infrastructure in the longer run. Secondly, it developed guidelines for the good use of the revenues from SMC pricing. Finally, it examined current practice and the use of the guidelines on a set of case studies.

The [GRACE](#) (2005-2007) project built upon the research carried out in [UNITE](#) and aimed to facilitate the implementation of pricing and taxation schemes that reflect the costs of infrastructure use (wear and tear, congestion, accidents and environmental) for all modes of transport. Case study research addressed gaps in the existing level of knowledge of marginal social costs for the various modes. A range of methodological improvements to transport accounts, with the aim of enabling their use as a monitoring tool for transport pricing reform, was proposed. In addition, a number of different charging regimes with different degrees of complexity were tested using a network modelling package. A generalisation of SMC estimates and the measurement of the impacts of SMC pricing were also provided.

The [DIFFERENT](#) project studied users' reactions to differentiated pricing as inputs to the wider policy-making process, notably the European Transport Policy. This was investigated through empirical (based on real-world case studies) and interrelated theoretical work. Furthermore, [DIFFERENT](#) analysed and demonstrated the benefits and effectiveness of differentiated charging and taxation schemes as a means of managing mobility, externalities and equity aspects, and to obtain revenues.

The main objective of the [FUNDING](#) project was to address the problems of the current funding framework for large European transport infrastructure. The economics of infrastructure funds and the mark-up method were explored conceptually. A set of scenarios was then developed, which ranged from heavy reliance on a European fund and low mark-ups on user prices for the new infrastructure to, at the other extreme, a small role for the European fund and an important role for the internal

funding of investments via mark-ups.

The [CATRIN](#) project addressed the allocation of infrastructure costs for all modes of transport so that pricing strategies based on the SMC principle can be implemented. Available studies on marginal infrastructure costs tend to allocate arbitrarily fixed, common and joint costs to vehicle types. However, using these studies for pricing purposes causes problems. Average costs are not the appropriate basis for efficient pricing.

The [ENACT](#) project investigated methods of applying SMC pricing within PPPs for the provision of transport infrastructure and services. The aim was to identify socially optimal levels for the pricing of transport services (or, at least, to second-best solutions). It addressed the main challenges of implementing SMC pricing (in particular, the conciliation between public and private interests and risk sharing around building and operating transport infrastructure) and contractual design elements. The theoretical review contributed to the development of a simulation tool that allowed the assessment of six case studies.

Looking at national research projects, the '[Design of a system creating a fair transport market environment, including harmonisation of traffic infrastructure pricing](#)' (2005-2007) study, funded by the Czech Republic, aimed to establish equal conditions (including pricing) for carriers and other transport infrastructure users.

The '[New models for the funding of transport infrastructure services](#)' (2001-2002) study, funded by the Ministry of Transport and Communication of Finland, looked into issues concerning the funding of the transport infrastructure and drafted a proposal for a stepwise path to develop the funding of transport infrastructure services.

#### 4.3.2.2 Financing

Closely linked to the research on pricing, an area of research developed the theme of financing the transport infrastructure.

The [INFRAFIN](#) project aimed to develop adequate and realistic financing schemes for TEN-T infrastructure projects, including, but not confined to, approaches based on PPPs.

A handbook giving practical guidelines on evaluating the costs of urban mobility and selecting ways to finance it was produced in the [FISCUS](#) project. It defined a framework for evaluating the real costs of urban transport with the objective of enabling cost comparisons between public transport and the private car. It also addressed the appropriate choice of a financing scheme, explaining the relative merits of new mechanisms such as private finance, value capture and cross funding.

The [PROFIT](#) project provided a comprehensive methodological framework for assessing the PPP potential of a TEN-T project. The [PROFIT](#) methodology was developed into a practical handbook that presents a step-by-step approach to guide the reader through the PPP process.

The aim of the TUD COST Action TU1001 project was to develop a theoretical basis for PPPs in the transport sector. The following objectives were addressed on a national and modal perspective:

- developing a decision-making process for selecting, implementing and operating PPP transport projects, considering sustainable procurement and value propositions;
- identifying critical success factors, test criteria and knowledge bases for improved PPP performance;
- identifying the implications of the financial arrangement.

The findings focused on the national context and the modal (urban, surface and port) context, respectively.

In the [BENEFIT](#) (2014-2016) project, funding and financing schemes were analysed and the key elements in transport infrastructure provision, operation and maintenance were described. These include business models, funding and financing schemes, implementation context, transport mode and contracting arrangements. The analyses considered their characteristics and attributes – a clustering of these will be the basis of a generic framework. Identifying best matches in their interrelations and where to intervene allows movement from a generic framework to a powerful decision policy tool, which can assess funding schemes for investments in infrastructure. The following relevant national studies have been identified:

- [Public services and infrastructures: regulatory, financial and institutional problems](#) (2004-2006), funded by the Italian National Research Council (CNR). This addressed some current regulation problems, mainly from a practical point of view. The topics addressed included the allocation of property rights in networks, the structure of the regulatory contract between regulator and regulated service providers, and the contracting out of services through auctions.
- The Swiss [NRP 54 – B3 Privatisation of financing and sustainability of urban infrastructures](#) (2008-2010) study demonstrated how the intervention of new financial actors was modifying the delivery of sustainability in the case of urban infrastructure.

### 4.3.3 Research outcomes

#### 4.3.3.1 Achievements of the research under this sub-theme

Over the past two decades, significant progress has been achieved in the research under this sub-theme.

Research on the issue of a more efficient pricing system has made remarkable progress in establishing a theoretical framework and improving valuation methodologies for impacts and costs.

The earlier studies illustrated that SMC may be estimated for a range of circumstances in a range of countries. They suggested that a purely commercial approach to transport pricing is not appropriate and may push prices in the wrong direction. This is because of the prevalence in the transport sector of economies

of scale, including the Mohring effect (which is the observation that, if an increase in demand for a transport service leads to an increased frequency of that service, it also leads to a reduction in waiting times for the passengers) and the importance of externalities.

Over time, the research focus has moved from the first stages of an implementation pathway to more mature stages of designing and implementing structured pricing policies. Methodologies for estimating the SMCs of the different modes have developed and been tested.

A significant body of European research investigated the likely impacts of pricing reforms on travel demand, encompassing modelling and demonstration studies. The results suggested that, in many circumstances, simple pricing reforms can achieve extensive benefits.

In those cases where, given real-world constraints, the pricing principle to be followed is not the theoretically optimal one of establishing prices equal to SMC, some forms of 'second-best' pricing principles have been identified and studied in depth.

Appropriate strategies have been established and discussed for the development of transition phases from the existing situation to one in which marginal-cost-based pricing will be implemented. The appropriate packaging of policies to achieve this has been identified. Research into public and political acceptability has assisted in the design of pricing systems that maximise acceptability and the likelihood of implementation.

Research on funding and financing forms has developed the theoretical basis for PPPs in the transport sector, addressed the main challenges of the implementation of marginal cost based pricing for PPPs (in particular, the conciliation between public and private interests, and risk sharing around building and operating transport infrastructure) and contractual design elements.

#### 4.3.3.2 Transferability from research to practical use

Some research progress has been translated into current practice. An example is the establishment of the 'Eurovignette Directive' (Directive 2011/76/EU amending Directive 1999/62/EC). This sets common rules at the European level on distance-related tolls and time-based user charges (vignettes) for heavy goods vehicles using certain infrastructure with the aim of better reflecting the principles of fair and efficient pricing.

Moreover, EU legislation requires transparent and non-discriminatory rail access charges, based on the principles of short-run SMCs, but with mark-ups permitted where it is necessary to satisfy financial requirements (Directive 2001/14, on the allocation of railway infrastructure capacity and levying of charges).

The practical use of research results in urban areas – where pricing can be applied to reduce congestion and environmental degradation, and to generate finance – is more limited, even if the implementation of pricing reform on roads is gathering pace in urban transport.



The application of congestion charges on urban roads is restricted to a few cities including London, Stockholm, Milan, Gothenburg, Oslo, Bergen and Trondheim, and smaller Norwegian towns.

The translation of research into current practice in the air and maritime transport sectors is still in its infancy. Although, in some cases, a price differentiation has been introduced to encourage sound environmental performance, in these sectors charges are largely based on commercial rather than social costs.

#### 4.3.3.3 Indications for future research

It can be concluded that the large amount of research carried out in this sub-theme has not been completely assimilated. This is because there remains a major need to synthesise and disseminate the results of existing research and to support additional research activities to identify ways of translating these into actions.

Additionally, given the generally low acceptance of infrastructure charging in the road sector, further research investigating how

to increase public and political acceptability of charging aimed at correcting the sector's externalities would be beneficial.

#### 4.3.3.4 Implications for future policy development

Correct pricing, and applying the 'user pays' and 'polluter pays' principles, are ways of making users of the transport infrastructure aware of the impact of their mobility choices. Nonetheless, several cases show that these principles are not always adhered to, resulting in a lack of consistency of infrastructure pricing across modes and Member States. Therefore, future policy development should pursue the objective of achieving a more streamlined and standardised approach to infrastructure charging that is based on sound and consistent pricing criteria that have been widely researched.

#### 4.3.4 List of projects

Table 4-3 lists the more significant projects included in the review of this sub-theme.

**Table 4-3 Projects reviewed in the pricing, funding and financing sub-theme**

Project acronym	Project name	Project duration	Source of funding
BENEFIT	Business Models for Enhancing Funding and Enabling Financing of Infrastructure in Transport <a href="https://goo.gl/QxpVWx">https://goo.gl/QxpVWx</a>	2014-2016	EU (IEE)
CATRIN	Cost Allocation of Transport Infrastructure Cost <a href="https://goo.gl/2ybMEx">https://goo.gl/2ybMEx</a>	2005-2009	EU (FP6-SUSTDEV)
DIFFERENT	User Reaction and Efficient Differentiation of Charges and Tolls <a href="https://goo.gl/IC2Gul">https://goo.gl/IC2Gul</a>	2006-2008	EU (FP6-SUSTDEV)
ENACT	Design Appropriate Contractual Relationships <a href="https://goo.gl/9xxIo0">https://goo.gl/9xxIo0</a>	2007-2009	EU (FP6-SUSTDEV)
EUROTOLL	European Research Project for Toll Effects and Pricing Strategies <a href="https://goo.gl/zEQCbK">https://goo.gl/zEQCbK</a>	1996-1999	EU (FP4)
FISCUS	Cost Evaluation and Financing Schemes for Urban Transport Systems <a href="https://goo.gl/6gMMKb">https://goo.gl/6gMMKb</a>	1998-1999	EU (FP4)
FUNDING	Funding Infrastructure: Guidelines for Europe <a href="https://goo.gl/GzBwHV">https://goo.gl/GzBwHV</a>	2005-2008	EU (FP6-SUSTDEV)
GRACE	Generalisation of Research on Accounts and Cost Estimation <a href="https://goo.gl/V8WQSu">https://goo.gl/V8WQSu</a>	2005-2007	EU (FP6-SUSTDEV)
INFRAFIN	Financing of Infrastructure Investments <a href="https://goo.gl/g0aPvS">https://goo.gl/g0aPvS</a>	1997-1998	EU (FP4)
MC-ICAM	Implementation of Marginal Cost Pricing in Transport – Integrated Conceptual and Applied Model Analysis <a href="https://goo.gl/U0mtf0">https://goo.gl/U0mtf0</a>	2001-2003	EU (FP5-GROWTH)
PATS	Pricing Acceptability in the Transport Sector <a href="https://goo.gl/4vRymP">https://goo.gl/4vRymP</a>	1999-2000	EU (FP4)
PETS	Pricing European Transport Systems <a href="https://goo.gl/WlUk1x">https://goo.gl/WlUk1x</a>	1996-1999	EU (FP4)

Table 4-3 (continued) Projects reviewed in the pricing, funding and financing sub-theme

Project acronym	Project name	Project duration	Source of funding
PROFIT	Private operation and financing of trans-European networks <a href="https://goo.gl/vH3bnn">https://goo.gl/vH3bnn</a>	1999-2000	EU (FP4)
RCI	Road charging interoperability pilot project <a href="https://goo.gl/OOPDOR">https://goo.gl/OOPDOR</a>	2005-2008	EU (FP6-SUSTDEV)
RECORDIT	Real Cost Reduction of Door-to-door Intermodal Transport <a href="https://goo.gl/4OWfFi">https://goo.gl/4OWfFi</a>	2000-2002	EU (FP5-GROWTH)
REVENUE	Revenue Use from Transport Pricing <a href="https://goo.gl/aMVkpz">https://goo.gl/aMVkpz</a>	2003-2005	EU (FP5-GROWTH)
TIPMAC	Transport Infrastructure and Policy: a macroeconomic analysis for the EU <a href="https://goo.gl/hTpkxj">https://goo.gl/hTpkxj</a>	2001-2003	EU (FP5-GROWTH)
TRANSPRICE	Trans Modal Integrated Urban Transport Pricing for Optimum Modal Split <a href="https://goo.gl/GJxOE9">https://goo.gl/GJxOE9</a>	1996-1998	EU (FP4)
TRENEN II STRAN	Models for Transport Environment and Energy – version 2 – Strategic Transport Policy Analysis <a href="https://goo.gl/Bz7rrY">https://goo.gl/Bz7rrY</a>	1996-1998	EU (FP4)
TUD COST Action TU1001	Public Private Partnerships in Transport: Trends and Theory <a href="https://goo.gl/ze19G9">https://goo.gl/ze19G9</a>	N/A	EU
UNITE	UNification of accounts and marginal costs for Transport Efficiency <a href="https://goo.gl/8pMbn1">https://goo.gl/8pMbn1</a>	2000-2003	EU (FP5-GROWTH)
N/A	New models for the funding of transport infrastructure services <a href="https://goo.gl/e6ujPT">https://goo.gl/e6ujPT</a>	2001-2002	Finland
N/A	Public services and infrastructures: regulatory, financial and institutional problems <a href="https://goo.gl/2wIVxr">https://goo.gl/2wIVxr</a>	2004-2006	Italy
N/A	Design of a system creating a fair transport market environment, including harmonisation of traffic infrastructure pricing <a href="https://goo.gl/8ZxgKL">https://goo.gl/8ZxgKL</a>	2005-2007	Czech Republic
NRP 54 – B3	Privatisation of financing and sustainability of urban infrastructures <a href="https://goo.gl/ZdOmyv">https://goo.gl/ZdOmyv</a>	2008-2010	Switzerland

## 4.4 Construction

### 4.4.1 Introduction to the sub-theme

Construction of transport infrastructure is a time and cost-intensive process that adversely impacts the environment. Research and innovation in this field can bring substantial benefits for infrastructure owners and users, and can contribute to addressing the challenges identified in the European Commission's 2011 Transport White Paper (European Commission, 2011). Therefore, the construction of transport infrastructure is an important research topic that is substantially supported at European and national levels.

Innovation and improvements in construction technologies and materials can reduce on-site construction time, improve the quality of the infrastructure once it has been constructed,

considerably reduce the total costs of ownership and maintenance, and extend the lifetime of infrastructure. Research into new materials and technologies, including the wider use of recycled materials and by-products, can minimise the use of raw materials, reducing the carbon footprint and cost of construction. It can also minimise land take and the impact on third parties. This latter aspect is particularly important in the urban environment. Good design of transport and ancillary infrastructure can improve safety, accessibility, cost-effectiveness and environmental performance, and provide better aesthetics and comfort, which is especially beneficial for passenger transport. At the same time, the infrastructure should not be oversized, the capacity should match the anticipated demand and it should not generate additional traffic.

#### 4.4.1.1 Overall direction of European-funded research

Transport infrastructure must be continuously improved to cope with increased transport volumes; changing logistics models; and challenges related to the environment (mainly emissions of gaseous and particulate pollutants and noise), safety and accessibility. These requirements have led to a large number of research projects within the various FPs over the past two decades. During this period, the majority of research projects concentrated on road and rail transport, although other transport modes such as air and water (e.g. the [CO-PATCH](#) (2010-2012) and [CYCLADES](#) (2012-2015) projects) were covered.

In general, there is an overall trend away from projects focused on important, but specific, research topics towards more comprehensive projects solving the whole context of infrastructure of the future and integrating the existing infrastructure systems and modes (e.g. the [FOX](#) (2015-2017) and [REFINET](#) projects). The preparation of a new, green, holistic and EU-harmonised certification system integrating life-cycle engineering (LCE) for road products and infrastructures (e.g. the [LCE4ROADS](#) (2013-2016) project, which was previously known as [ECOLABEL](#) (2013-2016)) is another dimension of this trend. Developments in information technologies, and increasing environmental and economic challenges have also influenced the research topics.

The projects supported by FP5 and FP6 focused on improvements in standards, the quality of road infrastructure (e.g. the [ARCHES](#) (2006-2009) and [SPENS](#) (2006-2009) projects); construction materials and transport safety (e.g. the [RISER](#) (2003-2006) and [SAFET](#) (2003-2006) projects); and environmental issues in road and rail transport (e.g. the [INQUEST](#) (2008-2008), [ITARI](#) (2004-2007) and [DIRECT-MAT](#) (2009-2011) projects). A special effort was concentrated on reducing environmental noise. In 2008, the European Commission initiated the development of harmonised methods for assessing noise exposure in Europe. In the [CNOSSOS-EU](#) (2010-2012) project, which was led by the European Commission's Joint Research Centre (JRC) on behalf of the Directorate General for Environment (DG ENV), the core of the common noise assessment methodological framework in Europe was developed. This framework focused on strategic noise mapping and balanced the need for harmonisation with the principles of proportionality and sectoral specificities in EU Member States (e.g. regarding data requirements).

After the enlargement of the EU in 2005, projects supporting the improvement and development of transport infrastructure in the new EU Member States in central and eastern Europe were conducted (e.g. the [ARCHES](#) and [CERTAIN](#) (2006-2010) projects). A particular focus was on improving the standards of the highway structures in those countries.

The FP7 projects addressed technologically demanding infrastructure such as tunnels, underground construction (e.g. the [SCOUT](#) (2005-2007) project) and bridges. The possibilities of electric charging, increases in safety (e.g. the [ROSATTE](#) (2008-2010) project) and solving environmental

issues, including noise from road and rail infrastructure (e.g. the [QUIET-TRACK](#) (2013-2016) and [ROSANNE](#) (2013-2016) projects), were also investigated. In 2014, the [INFRAVATION](#) (2014-2018) call was initiated as a pooled research fund to develop transport infrastructure innovations. It is supporting nine projects with a focus on road infrastructure materials and bridges. The INFRAVATION call was supported through the FP7 2013 work programme and included 11 European countries. For the first time, the United States of America (USA) also contributed to the funding.

The newest projects financed under Horizon 2020 focus on bridge construction, involving intelligent transport systems (ITS), modelling used in construction and design, and harmonising and standardising technologies and design, solutions (e.g. the [SECURESTATION](#) (2011-2014) and [URBAN TRACK](#) (2006-2010) projects). Developing a highly efficient and effective cross-modal research and development environment and culture that meets the demanding requirements of the transport and connectivity is the main aim of the current projects FOX and REFINET. Another current project, [SOLUTIONS](#) (2013-2016), aims to bridge the 'implementation gap' between the potential of innovative sustainable mobility and transport solutions (and packages of solutions), and the actual level of uptake and quality of the deployment mechanisms in cities. The [USE-IT](#) (2015-2017) project brings together infrastructure owners, transport operators and other important stakeholders to improve resource efficiency; reduce environmental impact; and provide safe and seamless transport for the benefit of citizens, the economy and society.



#### 4.4.1.2 Overall direction of nationally funded projects

National research in this sub-theme has involved a large variety of topics and research issues. In comparison with the EU-funded research, the national projects focused more on:

- the design of streets and interchange terminals (e.g. the [Rapid Construction of Passenger Interchanges](#) (2001-2005) project);
- traffic calming (e.g. the [Alternatives to pedestrian crossings in limited speed zones 30 km/h](#) (2008-2011)) and [Flexibility in planning of streets and public spaces/flexible traffic areas](#) (2009-2013) projects);
- cycling infrastructure and safety issues (e.g. the [Testing the system quality of road infrastructure design aimed at operational safety in actual traffic conditions](#) (2004-2006) project).

A number of projects dealt with e-mobility (e.g. the [E-BUS BERLIN](#) (2013-2016), [eMoVe](#) (2012-2015) and [GuEST](#) (2013-2015) projects). A specific focus has been on using pavements<sup>21</sup> to produce solar energy; here we should mention the 5-year French research programme, Wattway, which has culminated in the commercialisation of the technology that was developed.

#### 4.4.2 Research activities

The projects presented here are intended to cover a wide range of applications and transport modes, and highlight the diversity of ongoing research in Europe, funded by the EU and national funds. The research activities are divided into four topics:

- smarter design;
- advanced construction techniques;
- innovative material;
- ancillary infrastructure.

##### 4.4.2.1 Smarter design

Projects under this sub-theme focus on the smarter design of terminals, public transport infrastructure, roads, highways and pavements. They aim to improve safety, accessibility, cost-effectiveness and environmental performance, and to provide better aesthetics and comfort of public spaces. The planning and design require global approaches, centred more on 'human' aspects than on technical aspects only. For example, the [ARTISTS](#) (2001-2004) project set out an approach to the design and management of arterial streets from a people-oriented perspective. This meant that:

- street users – people rather than vehicles – were taken as the starting point for the analysis and redesign of street space;
- local stakeholders – people – were taken into account and included in the design and management process.

Human aspects also attracted the attention of various national projects, with a particular emphasis on safety. The [Car drivers' choice of speed in relation to the street's and environment's geometrical characteristics](#) (2003-2005) project provided an analysis of variables that describe a street's geometrical design and their effects on vehicle speed. This project contributed to an understanding of how a car driver's choice of speed can be influenced by using different types of street design. The 'Testing the system quality of road infrastructure design aimed at operational safety in actual traffic conditions' project appraised the quality of road projects. It took into consideration the behaviours that drivers adopt when faced by the physical and functional characteristics of rural road infrastructure under different traffic conditions. It verified the level of service of a road and the quality of the road design through an articulated system of 'indicators', which are able to explain and foresee the driving 'mistakes' that are solicited by the local and system structural characteristics of the road environment. The [Ex-post analysis of the spatial impact of transport infrastructure – Case study of Zurich S-Bahn](#) (2003-2004) project studied the effects of spatial changes in underground stations. The 'Flexibility in planning of streets and public spaces/flexible traffic areas' project studied the flexibility in planning streets and public spaces, and flexible traffic areas. In each case, the aim was to demonstrate how operational, constructional and ecological free space can be created by departing from usual technical standards and guidelines (e.g. speed and carriageway width).

The projects analysed differ in their approaches to 'design' and factors that are considered and studied in relation to the design (environmental, safety, accessibility, etc.). For example, the [SAMARIS](#) (2003-2006) project looked at how to consider environmental performance in the design and use of recycled components in materials for road construction. The project focused on preparing for the harmonisation of European approaches to material specification within the next generation of the European Committee for Standardization (CEN) standards. The [UNIACCESS](#) (2005-2006) project studied how a better design can decrease maintenance costs; increase safety; and offer better, easier and more comfortable access, particularly for passengers with reduced mobility.

Safety issues were considered in a significant number of the projects analysed. The [RISER](#) project looked at links between roadside infrastructure, and safety and operational issues. The [PROS](#) (2012-2014) project considered the safety aspects of a pan-European network. The [SECURESTATION](#) project was aimed at improving the resilience of passenger stations and terminals to terrorist attacks and safety incidents. It investigated technologies and methodologies enabling designers to reduce the impact of blast, fire and the dispersion of toxic agents on passengers, staff and infrastructure.

<sup>21</sup> In this context, 'pavement' refers to the material laid down on an area intended for vehicular traffic.



Models have been used to assist in the design of road surfaces and to predict their essential properties. For example, the AVATARS (2005-2007) project focused on modelling and developing simulation tools. AVATARS considered performance and comfort as major issues, and suggested better rail terminal designs that would provide increased passenger throughput and less overcrowding. Its simulations were applied to passenger evacuation plans and, specifically, to general circulation movements in and around rail terminals in normal circulation behaviour.

From the perspective of transport modes, the following projects dealt with the topic of smarter design:

- rail transport infrastructure and terminal design (e.g. the AVATARS and INFRASTAR (unknown-2000) projects);
- rail/tram track infrastructure design (e.g. the PMnIDEA (2009-2012) project);
- shipping (e.g. the HTA (2006-2011) and CYCLADES projects);
- road and pavement design (e.g. the ROSANNE and SECURESTATION projects);
- public transport (e.g. the UNIACCEESS project).

A strategic approach towards the improvement of transport infrastructure was taken by the FP6 NR2C (2003-2007) project. It sought conceptual and technical answers to the mobility and transport demands of the future, while aiming to generate future-oriented initiatives for addressing accessibility problems and issues related to road infrastructure. The project provided long-term perspectives for road infrastructure ('Vision 2040<sup>22</sup>'), which reconciled future transport needs, expected users, and social demands and sustainability goals. New concepts for the roads of the future (high-quality, cost-effective, low-noise, lower environmental impact, safer, risk-mitigating and low-maintenance, while facilitating traffic mobility and intermodality) were developed.

A research field with direct policy implications is focused on possibilities to improve the existing transport infrastructure in a revolutionary manner. The FOR (2011-2016) project aims to develop a concept of the 'fifth-generation road' – a road that is adaptable, automated and climate-change resilient, and is based upon a concept for building and maintaining roads that can be applied to any type of road (motorway, rural or urban) in any region or country. The road is adaptable to future changes in capacity demand and vehicle manufacturer needs. It automatically provides in-built vehicle guidance, travel information and performance measurement. The road is built from sustainable materials; harvests, stores and uses energy; copes with excess water and temperature change; and is able to clean and repair itself.

The overall aim is for roads to be 'forever open', with minimum intervention for repairs and widening, new installations or dealing with weather hazards. The key to this new approach is the 'adaptable element', which is formed from prefabricated,

upgradable pavement structures that have a long life. The adaptable element accommodates the automated and climate-change resilient elements.

The FOX project is attempting to network all transport modes (road, rail, water and air) to create an improved, integrated and functioning transport system for Europe. This is despite the limited financial resources of the owners of the transport network.

Together with the REFINET project, the FOX project has adopted an innovative and comprehensive approach towards the future development of transport infrastructure. These projects are trying to define the main features of future infrastructure. In addition to the characteristics of the future infrastructure as described in the NR2C project, they focus on adaptability; resilience and increasing capacity; provisioning of information and communications technology; and the capability to harvest, store and use energy.

The FOX project aims to identify common needs and innovative techniques in the areas of construction, maintenance, inspection, and recycling and re-use of transport infrastructure. The project is based on a phased approach, with all stakeholders (owners, researchers and industry) involved. Starting with determining the 'state of the art' as far as research and practice are concerned, the most promising practices and ideas will be identified during the next step. By mapping the common needs, the final aim is to establish a cross-modal working group to develop a roadmap for the whole transport sector and to set the agenda for further improvement of cross-modal research and development innovation.

The REFINET project aims to create a sustainable network of European and international stakeholders' representatives from all transport modes and transport infrastructure sectors. It also aims to deliver a shared European vision of how to specify, design, build, or renovate and maintain the multimodal European transport infrastructure network of the future. The REFINET project will consider two complementary scenarios:

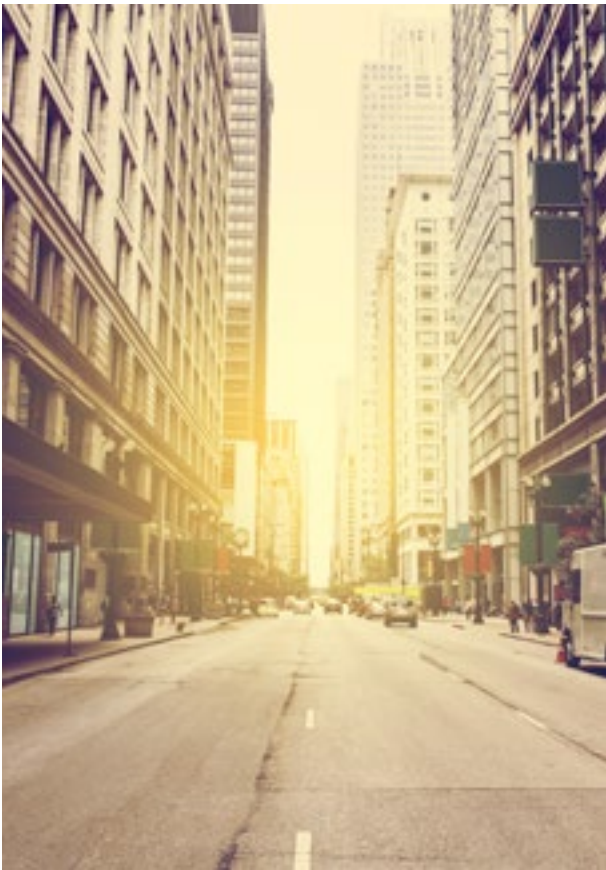
- maintaining and upgrading existing transport infrastructure;
- developing new transport infrastructure.

REFINET will contribute to creating a Europe-wide consensus on where to focus, in terms of research and innovation, to:

- improve the productivity of the assets (reducing maintenance costs and extending the life span);
- drastically reduce traffic disruptions due to inspection, construction and maintenance activities;
- accommodate increasing/changing traffic demand.

The harmonisation and eco-labelling of road transport is the subject of the LCE4ROADS project. It aims to bring an EU-harmonised methodology for cost-effective, safer, and greener road products and infrastructure.

<sup>22</sup> See <http://nr2c.fehrl.org/>



Most research analysed was found to concentrate on road transport. Other transport modes are on the edges of research interest, as is the integration of transport modes into a single system to substantially improve its performance through cross-modality. The possibilities of new and revolutionary approaches should also be considered for other modes – rail, inland waterway, maritime and air. The first step in this field is the Federation of European Highway Research Laboratories (FEHRL) programmes (in existence since 2013) of Forever Open Roads, Forever Open Railway, Forever Open River and Forever Open Runway. Together, these four programmes constitute the [FORx4](#) initiative on transport infrastructure. This is a European programme of research and development that tries to integrate transport modes (road, rail, water and air) with four shared domains to form a holistic transport system for the future (i.e. technology, infrastructure, governance and customers).

Due to the strong technical overlaps in the infrastructure requirements, many complementary research activities are planned in other modes (e.g. bridges, earthworks, materials and others).

#### 4.4.2.2 Advanced construction techniques

The construction of transport infrastructure is connected with ambitious demands such as better, quicker and cheaper production, construction and maintenance. To minimise the downtime of roads for maintenance activities, the overall quality of the construction has to be upgraded. The time slots available for repair and rehabilitation works are becoming tighter, which means that maintenance techniques have to become quicker. Furthermore, the environmental regulations

with respect to air pollution and noise emissions from traffic, and the use of raw materials are becoming more stringent.

The technical and environmental parameters and their harmonisation throughout Europe in particular have been the focus of several projects. For example, the ROSANNE project was aimed at the harmonisation of measurement methods for skid resistance, noise emission, rolling resistance of road surfaces and the preparation for standardisation. More precisely, the objectives of the project were:

- **Skid resistance** – the harmonisation of skid resistance measurement by deriving conversion factors for friction indices based on similar groups of devices, namely longitudinal and sideways skid resistance measurement devices.
- **Noise emission** – combining the existing measurement methods (statistical pass-by (SPB) and close-proximity method (CPX)) into a harmonised pavement-noise-emission characterisation method. An evaluation of its viability for acceptance testing, monitoring and compatibility with environmental noise calculation methods like CNOSSOS-EU was carried out. Remaining problems with the method, such as the influence of temperature, were addressed and solved as well.
- **Rolling resistance** – standardising trailer measurements of rolling resistance coefficients of road surfaces.
- **Texture** – exploring the potential for recent developments in the measurement of surface texture to deliver parameters that reflect the physical process of tyre/road interaction better and that may improve our understanding of how the texture influences skid resistance, noise emission and rolling resistance.
- **Reference tyres and pavements** – defining and investigating the performance of reference tyres and pavements necessary for the measurement of the first three road surface properties listed above. This is a prerequisite for the harmonisation of all future measurements.

The [COST 351 – WATMOVE](#) (2003-2007) project focused on improving highway performance and minimising the leaching of contaminants from roads. The project:

- analysed water movement and moisture conditions in unbound pavement layers and subgrades for different types of road constructions in various climatic conditions;
- investigated the relationship between the mechanical behaviour of materials/soils and their hydraulic conductivity and moisture conditions.

The ITARI project used the virtual design of road surfaces and their essential properties, including tools for designing:

- low noise surfaces based on a hybrid simulation model for tyre/road noise;
- a tool for predicting rolling resistance as a function of surface properties;
- a tool for predicting wet grip.

Safe utilisation of seawater and salt-contaminated aggregates (natural or recycled) for sustainable concrete production when combined with non-corrosive reinforcement to construct durable and economical concrete infrastructures are being analysed by the [SEACON](#) (2015-2018) project.

Particular attention was paid to various technical challenges connected with more complex infrastructure such as bridges, underground constructions and tunnels. The construction improvements in bridges employ new materials, and design and construction processes developed through a number of research projects (e.g. the [HP FUTURE-BRIDGE](#) (2006-2009) project and three ongoing projects supported by INFRAVATION ([FASSTBRIDGE](#) (2015-2018), [SEEBRIDGE](#) (2015-2018) and [SUREBRIDGE](#) (2015-2018)). An innovative repair technology for large steel structures with defects was studied by the CO-PATCH project.

The overall objective of the HP FUTURE-BRIDGE project was to develop a new high-performance and cost-effective construction concept for bridges that was based on applying fibre-reinforced polymers (FRP) for rapid renewal and providing a longer lasting repair. Cost-effectiveness was achieved by optimising materials and design, and reducing manufacturing costs and lead times. Similarly, high-performance structures required performance-based design and manufacturing, and new materials. The energy efficiency and environmental impact of the whole life-cycle of the bridge was improved by reducing energy consumption in the on-site manufacturing process and the transportation of materials, and by improving recyclability through using new thermoplastic resins.

The FASSTBRIDGE project aims to achieve drastic reductions in the economic and environmental costs of ownership of the steel bridge stock in Europe and the USA. Its solution will be based on an easy-to-apply methodology (fatigue lifetime assessment, design, execution and maintenance guideline) to prevent the evolution of irreversible fatigue problems at a pre-failure scenario. The SUREBRIDGE project will propose a solution for using the remaining capacity of the superstructure in existing bridges by preserving the relevant structural elements such as girders and concrete deck. The SEEBRIDGE project will develop bridge object detection software to recognise distinct 3D solid geometries from the point cloud data. An expert system, using encoded bridge engineers' knowledge, will be used for the classification of bridge components and for the deduction of supplementary information concerning material types, internal bridge components, etc. A damage measurement tool will also be devised to associate the identified damage to the 3D model at the bridge component level.

The construction of tunnel walls and their optimisation has been studied by the SCOUT project. Its core activities included developing new methods for design to optimise the engineering of cut-and-cover projects, using the concept of a 'double skin' structure and aiming to reduce the cost of construction materials. It also included the development of a radically new concept for constructing tunnel walls, where the drilling process is continuous and horizontal, with the objectives of minimal environmental impact and maximum safety for workers.

The project also studied new composite materials, and how fibre-reinforced-concrete materials can be used in temporary and permanent structure members to optimise structural design.

Projects aimed at railway infrastructure improvements included systems for noise mitigation (e.g. the [QUIET-TRACK](#) (2013-2016) project) and improving vehicle-track interaction of turnout systems (e.g. the [TURNOUTS](#) (2003-2007) project). Modular track infrastructure solutions were studied by the URBAN TRACK project, and flexible and cost-effective joining processes have been developed and demonstrated by the ongoing [WRIST](#) (2015-2018) project. The WRIST project focuses on joining processes for the more recently introduced bainitic rail steel grades, for which conventional welding techniques have been shown to be inadequate. New variants of the aluminothermic and orbital friction welding processes will be developed. These will reduce the width of the heat-affected zone and minimise the loss of mechanical properties in the weld zone. These innovations will enable the use of bainitic rail steels that will deliver increased reliability, a longer lifetime of the rails and welds, and reduced maintenance costs.

#### 4.4.2.3 Innovative materials

Several projects relating to this sub-theme were dedicated to research into the better use of existing materials such as asphalt (e.g. the [RE-ROAD](#) (2009-2012), [ALTERPAVE](#) (2015-2018), [BIOREPAVATION](#) (2015-2018), [DURABROADS](#) (2013-2017) and [HEALROAD](#) (2015-2018) projects) and concrete (e.g. the [SEACON](#) and [ECLIPS](#) (2015-2018) projects). There are also projects that contribute to the incorporation of recycled waste materials of different origins into building materials for roads to save on raw materials (e.g. the [BIOREPAVATION](#), [SPENS](#) and [DIRECT-MAT](#) projects).

Some research projects have focused on how to improve the quality of asphalt. The HEALROAD project is looking into a heating technique that is able to extend the lifetime of asphalt mixes by developing, optimising and validating asphalt mixture wearing courses and steel fibres to facilitate self-healing via induction heating. When micro-cracks appear in the wearing course (normally between 3 years and 5 five years after its construction), heating elements embedded in the road surface will be heated by electromagnetic induction. Bitumen will then melt and flow through the micro cracks to close them. Initial estimates from the project indicate that the lifetime of roads could be extended by over 30 % if this technology is used in combination with other maintenance methods.

The RE-ROAD and ALTERPAVE projects analysed the possibilities of replacing virgin aggregates with recycled materials (e.g. reclaimed asphalt pavement) and by-products (e.g. slag). These methods should enhance end-of-life strategies for asphalt road infrastructure and improve their energy efficiency and environmental footprint. Alternatively, green binders, such as waste engine oils and bio-fluxing agents, can be integrated into the mixes to reduce the use of petroleum-based binders. These techniques lead to a reduction in the need to use raw materials and prevent the creation of waste, so reducing the amount of material sent to landfill for disposal.





As a result, they minimise the need for transporting materials to and from the work site, so reducing energy consumption and pollution, including carbon dioxide emissions.

LCA and life-cycle cost (LCC) studies will be performed for the newly developed asphalt materials and the results will be compared with those for conventional materials. The BIOREPAVATION project aims to prove that alternative binders can be used to recycle asphaltic pavement materials with the same level of performance as conventional solutions using petroleum bitumen. The performance of the technology in demonstrations will be evaluated by measuring the time (or traffic level) taken for the structure to reach a distress mechanism (cracking, rutting, etc.) and by investigating the binder physico-chemical evolution using an innovative non-destructive method. The project will also assess the environmental impacts of the combined use of bio-binders and a high content of reclaimed asphalt in asphalt mixes. The airborne emissions produced will be directly measured at a laboratory. The data obtained will be used to perform a risk assessment and an LCA.

Thermal cracking in reinforced concrete elements and freeze-thaw related deterioration in concretes exposed to temperature cycling around the freezing point of water are sources of concern to owners and managers of infrastructure assets around the world. This is a considerable issue with numerous transportation structures (e.g. bridges and pavements), often requiring premature repair and replacement or incurring exceedingly high maintenance costs during their service life. The ECLIPS project tests the incorporation of phase-change materials (PCMs) with a suitable phase-transition temperature, enthalpy of phase change and degree of dispersion in the concrete as a way to alleviate each of these concerns. PCMs are combined sensible (or specific) heat and latent heat thermal storage materials that can be used to store and dissipate energy in the form of heat. On the other hand, the SEACON project is looking into the production of an innovative concrete that contains high chloride constituents (i.e. cement,

sea water and aggregates) in combination with non-corrosive reinforcement.

The main objectives of the [ECOLANES](#) (2006-2009) project were to develop, test and validate steel fibre reinforced concrete (SFRC) pavements by using roller-compaction techniques (based on existing asphalt-laying equipment) and recycled materials to reduce construction costs, construction time and energy consumption. The project investigated techniques and equipment for post-processing steel fibres produced from post-consumer tyres to produce fibres suitable for incorporation in concrete. These fibres were dispersed into concrete (wet and dry mixes). The project investigated slip-forming and roller-compaction techniques for SFRC that are similar to those used for asphalt laying and the development of SFRC mixes suitable for these forming techniques. Other aspects investigated included models for the design of long-lasting rigid pavements (LLRP) made with SFRC, life-cycle tools to determine costs, energy efficiency, the environmental impacts of new infrastructure and full-scale demonstration projects.

The remaining projects in this sub-theme focused on applying new materials for the rehabilitation of infrastructure – FRP for rapid renewal, providing a longer-lasting repair for infrastructure (e.g. the HP FUTURE-BRIDGE project) and ultra-high-performance fibre reinforced concrete for the rehabilitation of bridges (e.g. the SAMARIS and [SCOUT](#) (2005-2007) projects).

#### 4.4.2.4 Ancillary infrastructure

Moving the European transport system from its 20th century dependency on fossil fuels to an era powered by renewable sources of energy (e.g. hydrogen and electricity) requires a significant effort. Infrastructure is required for electricity or hydrogen production, storage and distribution. Facilities will also be needed for vehicle refuelling. This has implications for transport infrastructure since a widespread refuelling infrastructure is essential for customer acceptance.



Infrastructure ancillaries (e.g. road studs) can be powered by alternative energy sources, such as solar energy.

These issues have been explored by the [CHIC](#) (2010–2016) and [SMARTV2G](#) (2011–2014) projects. The CHIC project tested solutions for accelerating the development of clean, hydrogen-propelled public transport systems, while identifying the key challenges related to the planning and design of fuelling stations. The SMARTV2G project promoted the transition towards a smart vehicle to grid (V2G) system which contributes to implementing integrated plans for sustainable mobility and energy management.

Investigations into an easier and more comfortable charging solution that will enable the ease of use of electric vehicles (EVs) by the general public have been made by the [FASTINCHARGE](#) (2012–2015) and [UNPLUGGED](#) (2012–2015) projects. These projects investigated how a smart inductive charging infrastructure can facilitate full EV integration into urban road systems while improving customer acceptance and perceived practicality.

Wattway, a French national project, focused on another area of electricity supply, namely the use of the infrastructure for power generation through the construction of photovoltaic (PV) road surfaces. Wattway is a patented French innovation that is the result of 5 years of research undertaken by Colas, a world leader in transport infrastructure and the French National Institute for Solar Energy (INES). By combining road construction that is suitable for all traffic and PV technology, Wattway pavement provides clean, renewable energy in the form of electricity. Wattway is composed of PV cells inserted in superposed layers that ensure resistance and tyre grip. The composite material is just a few millimetres thick, making it possible to adapt to thermal dilation in the pavement and vehicle loads, a guarantee of durability and safety. Wattway can be applied directly on the current pavement, without any need for civil engineering work.

The use of alternative fuels has become increasingly important in the context of mobility policy and has been covered by several research projects that have considered the integration of non-fossil energy sources, and urban traffic and land use planning. The [CCS Berlin](#) (2013–2015) and [eMoVe](#) (2012–2015) projects sought to demonstrate the economic viability of hydrogen mobility and electromobility, including them in the urban planning process and encouraging the introduction of hydrogen-fuelled and EVs. They also considered the benefits of better integration of these technologies into mobility services. Previously, the [Electric power systems and transport systems within land use planning for sustainable development](#) (2002–2003) study looked at the integration of electric power systems and transport systems in land use planning for sustainable development. This study addressed the institutional frameworks and decision mechanisms that will be needed to allow electrically powered urban transport systems to be incorporated in land use policies.

The [INROADS](#) (2011–2014) project developed intelligent road studs (IRS) that combine light emitting diode (LED) technology, sensor systems and communication technologies. IRS have renewable energy technologies that fully or partially power

the devices, which makes them self-contained. Using PV and piezoelectric technologies reduces carbon emissions and allows IRS to be used on roads with no readily available power source.

## 4.4.3 Research outcomes

### 4.4.3.1 Achievements of the research under this sub-theme

The research projects under this sub-theme have brought practical results that can lead to substantial savings in construction and maintenance costs, and improvements in environmental impacts of the transport infrastructure. All areas of research analysed are developing outputs with practical applications, though they are particularly evident in the topics of advanced construction techniques and innovative materials. The expected savings in costs can be significant.

For example, new design tools for optimising structural design can bring cost savings of about 15 % on construction materials, with minimal environmental impacts (see the SCOUT project). Reinforced structures of bound and unbound pavement layers may prolong the service life of pavements by more than 20 % (see the SPENS project). Research in this field also brought effective repair methods for large steel structures with defects and demonstrated that composite patch repairs can be environmentally stable and, therefore, that they can be used as permanent repair measures. The composite patch repair technology (see the CO-PATCH project) is an innovative and highly competitive product that caters for the needs of marine vessels and civil engineering infrastructure. This technology creates a new market.

Regarding railways, an integrated family of ‘maintenance-free’ modular track infrastructure solutions, leading to a substantial reduction in global track infrastructure costs (target of 25 % of reduction in LCC) and a significant increase in the availability of track infrastructure, were developed and built. This track design was tested and planned to manage the demands placed on tram tracks (see the Urban Track or SCOUT projects). The modular architecture provides a high level of flexibility to cope with a variety of infrastructure configurations and soil profiles.

Diverse practical results were achieved in the field of research on construction materials – in particular, improvements in asphalt and concrete technologies, new materials using nanotechnologies, fibre-concrete composite materials and FRP. The innovative materials can substantially extend the lifetime of transport infrastructure and can contribute to more sustainable production by using recycled materials. For example, using self-healing road technologies with other maintenance actions can extend the lifetime of roads by more than 30 % (see the HEALROAD project). The improved materials are also better adjusted to new climate conditions (above all, extreme temperature changes) and to heavy traffic. The improved and new materials are used mainly in road (including bridges and tunnels) and rail infrastructure.

A specific output was delivered by French research. The product, Wattway, is the first example of combining road construction and PV techniques. The Wattway pavement provides clean, renewable energy in the form of electricity, while providing

a surface that is suitable for all types of traffic. Wattway is composed of cells inserted in superposed layers that ensure resistance and tyre grip. The composite material is just a few millimetres thick, making it possible to adapt to thermal dilation in the pavement and vehicle loads, a guarantee of durability and safety.

#### 4.4.3.2 Indications for future research

There has been rapid development in construction techniques and materials over recent decades. However, further progress and optimisation of the transport infrastructure is constantly needed. The transport infrastructure construction sector must address issues concerning the availability of natural resources, the quality of construction materials, climate conditions and the suitability of construction methods.

Research should support the sector with innovations and contribute to fulfilling the European policy objectives on climate, environment, energy and transport. For example, by focusing on improving materials and their characteristics, and generally making transport infrastructure more resilient and efficient. Further research should then concentrate on developing:

- fast, off-site construction methods;
- long life and more durable transport infrastructure;
- integrated models of urban (human) design;
- analyses of the alternative use of transport infrastructure with the aim of producing energy or improving the environment;
- analyses of whole-life costs.

The whole-life cost analyses should encompass:

- sustainable construction;
- reducing fuel consumption;
- reducing raw material use (such as concrete, steel and copper, which are used in the construction of transport infrastructure, but are often omitted from greenhouse gas balances);
- using secondary raw materials in road construction;
- low maintenance disruption.

Substantial research should be carried out into the concept of future design and co-operability of infrastructure. The FOR project suggests that future roads will require high levels of adaptation, automation and resilience. The adaptable road can be defined as one that focuses on:

- ways to allow road operators to respond in a flexible manner to changes in road users' demands and constraints;
- the full integration of intelligent communication technology applications between the user, vehicle, traffic management services and road infrastructure;
- ensuring service levels are maintained under extreme weather conditions.



Technological development, especially in the ITS sector, brings further research topics for transport infrastructure improvement. Cooperative intelligent transport systems (C-ITS) can rapidly increase the capacity of the existing and planned infrastructure. Therefore, the transport infrastructure will need to be able to provide for the communications and power systems that future vehicles and users will demand. Improving the functionality and integration of the transport infrastructure with processing, storing, integrating and making sense of the large amounts of data that will be generated, is a research challenge for the future.

Introducing electric or hydrogen-propelled vehicles requires the development and establishment of a comprehensive charging infrastructure. Research may concentrate on developing an intelligent, inductive charging infrastructure that enables the integration of the charging infrastructure with road infrastructure. In this regards, standardisation is essential to enable large-scale roll-out, so improving customer acceptance.

#### 4.4.3.3 Implications for future policy development

A functioning transport infrastructure and its continued reliability are the cornerstones of the economy. This can be achieved only if the next generation of transport systems incorporates new technology. Therefore, future policy development should also continue to support innovation and research in the field of transport infrastructure construction. The innovation and other research results should be applied directly to infrastructure investments, green public procurement procedures and further policies or standards that are legally enforceable. Policy should:

- emphasise the long-life assessment approach;
- reflect the need to improve resilience against extreme weather events of the overall transport system;
- reflect the need to increase capacity of the transport system as a whole through improvements to the existing network and managing demand and traffic.

Good governance can also encourage knowledge transfer and pool funding, and establish common methods and technologies between transport modes. Other important aspects are to support the use of transport infrastructure for energy generation, improve habitats and increase biodiversity around infrastructure assets.

Developing an EU-harmonised certification system that integrates an LCE approach for transport infrastructure

and standardisation for intelligent charging infrastructure represents another policy challenge.

#### 4.4.4 List of projects

Table 4-4 lists the more significant projects included in the review of this sub-theme.

**Table 4-4 Projects reviewed in the construction sub-theme**

Project acronym	Project name	Project duration	Source of funding
ALTERPAVE	Use of End-of-Life Materials, Waste and Alternative Binders as Useful Raw Materials for Pavements Construction and Rehabilitation <a href="https://goo.gl/mypeqN">https://goo.gl/mypeqN</a>	2015-2018	EU (FP7-TPT)
ARCHES	Assessment and Rehabilitation of Central European Highway Structures <a href="https://goo.gl/myL61n">https://goo.gl/myL61n</a>	2006-2009	EU (FP6-SUSTDEV)
ARTISTS	Arterial Streets towards Sustainability <a href="https://goo.gl/aK8Fv4">https://goo.gl/aK8Fv4</a>	2001-2004	EU (FP5-EESD)
AVATARS	Advanced Virtual Agents for Testing the Accessibility of Rail Stations <a href="https://goo.gl/FVBzLb">https://goo.gl/FVBzLb</a>	2005-2007	EU (FP6-SUSTDEV)
BIOREPAVATION	Innovation in Bio-Recycling of Old Asphalt Pavements <a href="https://goo.gl/Kdu1iN">https://goo.gl/Kdu1iN</a>	2015-2018	EU (FP7-TPT)
CERTAIN	Central European Research in TrAnsport INfrastructure <a href="https://goo.gl/Mryp7U">https://goo.gl/Mryp7U</a>	2006-2010	EU (FP6-INTEGRATING)
CHIC	Clean Hydrogen in European Cities <a href="https://goo.gl/fL8WXX">https://goo.gl/fL8WXX</a>	2010-2016	EU (FP7-JTI)
CNOSSOS-EU	Common Noise Assessment Methods in Europe <a href="https://goo.gl/q1ZmWO">https://goo.gl/q1ZmWO</a>	2010-2012	EU (JRC)
CO-PATCH	Composite patch repair for marine and civil engineering infrastructure applications <a href="https://goo.gl/BS4ANM">https://goo.gl/BS4ANM</a>	2010-2012	EU (FP7-TPT)
COST 351 - WATMOVE	Water Movements in Road Pavements and Embankments <a href="https://goo.gl/yKvI7S">https://goo.gl/yKvI7S</a>	2003-2007	EU (COST)
CYCLADES	Crew-centered Design and Operations of ships and ship systems <a href="https://goo.gl/pdbwsR">https://goo.gl/pdbwsR</a>	2012-2015	EU (FP7-TPT)
DIRECT-MAT	Dismantling and REcycling Techniques for road MATerials – sharing knowledge and practices <a href="https://goo.gl/eNgTDI">https://goo.gl/eNgTDI</a>	2009-2011	EU (FP7-SST)
DURABROADS	Cost-effective DURABLE ROADS by green optimised construction and maintenance <a href="https://goo.gl/XgzRGL">https://goo.gl/XgzRGL</a>	2013-2017	EU (FP7-TPT)
ECLIPS	Enhancing Concrete Life in Infrastructure through Phase-Change Systems <a href="https://goo.gl/iNDqmw">https://goo.gl/iNDqmw</a>	2015-2018	EU (FP7-TPT)
ECOLABEL	Development of a novel ECO-LABELing EU-harmonised methodology for cost-effective, safer and greener road products and infrastructures <a href="https://goo.gl/SMVGon">https://goo.gl/SMVGon</a>	2013-2016	EU (FP7-TPT)

Table 4-4 (continued) Projects reviewed in the construction sub-theme

Project acronym	Project name	Project duration	Source of funding
ECOLANES	Economical and Sustainable Pavement Infrastructure for Surface Transport <a href="https://goo.gl/Yorjli">https://goo.gl/Yorjli</a>	2006-2009	EU (FP6-SUSTDEV)
FASSTBRIDGE	Fast and effective – Solution for steel bridges life-time extension <a href="https://goo.gl/Uct4VL">https://goo.gl/Uct4VL</a>	2015-2018	EU (FP7-TPT)
FASTINCHARGE	Innovative FAST INductive CHARGing solution for Electric vehicles <a href="https://goo.gl/Ty84iL">https://goo.gl/Ty84iL</a>	2012-2015	EU
FOR	Forever Open Road <a href="https://goo.gl/V86Plv">https://goo.gl/V86Plv</a>	2011-2016	International
FOX	Forever Open infrastructure across (X) all transport modes <a href="https://goo.gl/qKMxEN">https://goo.gl/qKMxEN</a>	2015-2017	EU (Horizon 2020)
HEALROAD	Induction heating asphalt mixes to increase road durability and reduce maintenance costs and disruptions <a href="https://goo.gl/79DxZc">https://goo.gl/79DxZc</a>	2015-2018	EU (FP7-TPT)
HP FUTURE-BRIDGE	High-Performance (Cost Competitive, Long Life and Low Maintenance) Composite Bridges for Rapid Infrastructure Renewal <a href="https://goo.gl/524IMV">https://goo.gl/524IMV</a>	2006-2009	EU (FP6-SUSTDEV)
HTA	Hydro-Testing Alliance An Alliance to Enhance the Maritime Testing Infrastructure in the EU <a href="https://goo.gl/EZDcA5">https://goo.gl/EZDcA5</a>	2006-2011	EU (FP6-SUSTDEV)
INFRASTAR	Improving railway infrastructure productivity by sustainable two material rail development <a href="https://goo.gl/6RvsJO">https://goo.gl/6RvsJO</a>	Unknown-2000	EU (FP5)
INFRAVATION	ERA-NET Plus on Infrastructure Innovation <a href="https://goo.gl/yTTJl3">https://goo.gl/yTTJl3</a>	2014-2018	EU (FP7-TPT)
INQUEST	Information Network on Quiet European road Surface Technology <a href="https://goo.gl/5Qm6Y0">https://goo.gl/5Qm6Y0</a>	2006-2008	EU (FP6-SUSTDEV)
INROADS	INtelligent Renewable Optical ADvisory System <a href="https://goo.gl/8YAi7q">https://goo.gl/8YAi7q</a>	2011-2014	EU (FP7-TPT)
ITARI	Integrated Tyre and Road Interaction <a href="https://goo.gl/K1EkP6">https://goo.gl/K1EkP6</a>	2004-2007	EU (FP6-SUSTDEV)
LCE4ROADS	Development of a novel ECO-LABELing EU-harmonised methodology for cost-effective, safer and greener road products and infrastructures (formerly ECOLABEL) <a href="https://goo.gl/7lehr">https://goo.gl/7lehr</a>	2013-2016	EU (FP7-TPT)
NR2C	New Road Construction Concept <a href="https://goo.gl/1CsUZK">https://goo.gl/1CsUZK</a>	2003-2007	EU (FP6-SUSTDEV)
PMnIDEA	Predictive Maintenance employing Non-intrusive Inspection & Data Analysis <a href="https://goo.gl/geFGzv">https://goo.gl/geFGzv</a>	2009-2012	EU (FP7-TPT)
PROS	Priorities for Road Safety Research in Europe <a href="https://goo.gl/gHpbvJ">https://goo.gl/gHpbvJ</a>	2012-2014	EU (FP7-TPT)
QUIET-TRACK	Quiet Tracks for Sustainable Railway Infrastructures <a href="https://goo.gl/7SJ0VF">https://goo.gl/7SJ0VF</a>	2013-2016	EU (FP7-TPT)
REFINET	REthinking Future Infrastructure NETworks <a href="https://goo.gl/KKQNFQ">https://goo.gl/KKQNFQ</a>	2015-2017	EU (Horizon 2020)



Table 4-4 (continued) Projects reviewed in the construction sub-theme

Project acronym	Project name	Project duration	Source of funding
RE-ROAD	Re-Road End of Life Strategies of Asphalt Pavements <a href="https://goo.gl/SSDqxf">https://goo.gl/SSDqxf</a>	2009-2012	EU (FP7-TPT)
RISER	Roadside Infrastructure for Safer European Roads <a href="https://goo.gl/ZREiWv">https://goo.gl/ZREiWv</a>	2003-2006	EU (FP5-GROWTH)
ROSANNE	Rolling resistance, Skid resistance, AND Noise Emission measurement standards for road surfaces <a href="https://goo.gl/pZt2uu">https://goo.gl/pZt2uu</a>	2013-2016	EU (FP7-TPT)
ROSATTE	ROad Safety ATtributes Exchange Infrastructure in Europe <a href="https://goo.gl/dqGpzn">https://goo.gl/dqGpzn</a>	2008-2010	EU (FP7-ICT)
SAFET	Safety in tunnels Thematic Network <a href="https://goo.gl/CLVQjs">https://goo.gl/CLVQjs</a>	2003-2006	EU (FP5-GROWTH)
SAMARIS	Sustainable and Advanced Materials for Road Infrastructure <a href="https://goo.gl/7RMBHj">https://goo.gl/7RMBHj</a>	2003-2006	EU (FP5-GROWTH)
SCOUT	Sustainable Construction of Underground Transport Infrastructures <a href="https://goo.gl/zKddsy">https://goo.gl/zKddsy</a>	2005-2007	EU (FP6-SUSTDEV)
SEACON	Sustainable concrete using seawater, salt-contaminated aggregates, and non-corrosive reinforcement <a href="https://goo.gl/jl8kNb">https://goo.gl/jl8kNb</a>	2015-2018	EU (FP7-TPT)
SECURESTATION	Passenger station and terminal design for safety, security and resilience to terrorist attack <a href="https://goo.gl/n8DDtG">https://goo.gl/n8DDtG</a>	2011-2014	EU (FP7-SST)
SEEBRIDGE	Automated compilation of semantically rich BIM models of bridges <a href="https://goo.gl/t2su5y">https://goo.gl/t2su5y</a>	2015-2018	EU (FP7-TPT)
SHAPE	Predicting strength changes in bridges from frequency data safety, hazard, and poly-harmonic evaluation <a href="https://goo.gl/RhHVXE">https://goo.gl/RhHVXE</a>	2015-2018	EU (FP7-TPT)
SMARTV2G	Smart Vehicle to Grid Interface <a href="https://goo.gl/uBheEz">https://goo.gl/uBheEz</a>	2011-2014	EU (FP7-ICT)
SOLUTIONS	Sharing Opportunities for Low carbon Urban TransportatIOn <a href="https://goo.gl/omZjo6">https://goo.gl/omZjo6</a>	2013-2016	EU (FP7-TPT)
SPENS	Sustainable Pavements for EU New Member States <a href="https://goo.gl/1443xX">https://goo.gl/1443xX</a>	2006-2009	EU (FP6-SUSTDEV)
SUREBRIDGE	Sustainable Refurbishment of Existing Bridges <a href="https://goo.gl/5JH1ub">https://goo.gl/5JH1ub</a>	2015-2018	EU (FP7-TPT)
TURNOUTS	New Concepts for Turnouts in Urban Rail Transit Infrastructures <a href="https://goo.gl/lpKeXo">https://goo.gl/lpKeXo</a>	2003-2007	EU (FP6-SUSTDEV)
TYROSAFE	Tyre and Road Surface Optimisation for Skid Resistance and Further Effects <a href="https://goo.gl/lrqBkH">https://goo.gl/lrqBkH</a>	2008-2010	EU (FP7-TPT)
UNIACCESS	Design of Universal Accessibility Systems for Public Transport <a href="https://goo.gl/AUZYw5">https://goo.gl/AUZYw5</a>	2005-2006	EU (FP6-SUSTDEV)
UNPLUGGED	Wireless charging for Electric Vehicles <a href="https://goo.gl/vq5ory">https://goo.gl/vq5ory</a>	2012-2015	EU (FP7-TPT)
URBAN TRACK	Urban Rail Infrastructure <a href="https://goo.gl/wMRQPK">https://goo.gl/wMRQPK</a>	2006-2010	EU (FP6-SUSTDEV)

Table 4-4 (continued) Projects reviewed in the construction sub-theme

Project acronym	Project name	Project duration	Source of funding
USE-IT	Users, Safety, security and Energy In Transport Infrastructure <a href="https://goo.gl/UETJrb">https://goo.gl/UETJrb</a>	2015-2017	EU (Horizon 2020)
WRIST	Innovative Welding Processes for New Rail Infrastructures <a href="https://goo.gl/MyHFLa">https://goo.gl/MyHFLa</a>	2015-2018	EU (Horizon 2020)
N/A	Flexibility in planning of streets and public spaces/flexible traffic areas <a href="https://goo.gl/DbIYFX">https://goo.gl/DbIYFX</a>	2009-2013	Switzerland
N/A	Rapid Construction of Passenger Interchanges <a href="https://goo.gl/xdZlBL">https://goo.gl/xdZlBL</a>	2001-2005	United Kingdom
N/A	Testing the system quality of road infrastructure design aimed at operational safety in actual traffic conditions <a href="https://goo.gl/DzBeM3">https://goo.gl/DzBeM3</a>	2004-2006	Italy
CCS Berlin	Combined Charging System: Development and demonstration of rapid charging stations <a href="https://goo.gl/2pNAOF">https://goo.gl/2pNAOF</a>	2013-2015	Germany
E-BUS BERLIN	Fully electric bus operations including recharging infrastructure <a href="https://goo.gl/52GXMI">https://goo.gl/52GXMI</a>	2013-2016	Germany
eMoVe	Electromobility Moves Aachen <a href="https://goo.gl/AsRzab">https://goo.gl/AsRzab</a>	2012-2015	Germany
GuEST	Research into Usage of E-Taxis in Stuttgart <a href="https://goo.gl/X3czsZ">https://goo.gl/X3czsZ</a>	2013-2015	Germany
N/A	Electric power systems and transport systems within land use planning for sustainable development <a href="https://goo.gl/UkOP9z">https://goo.gl/UkOP9z</a>	2002-2003	Italy
N/A	Car drivers' choice of speed in relation to the street's and environments geometrical characteristics <a href="https://goo.gl/mkhlW6">https://goo.gl/mkhlW6</a>	2003-2005	Sweden
N/A	Development of decision support system for the design of transport infrastructure (VSS2000/339) <a href="https://goo.gl/EZqQWY">https://goo.gl/EZqQWY</a>	2002-2010	Switzerland
N/A	Ex-post analysis of the spatial impact of transport infrastructure – Case study of Zurich S-Bahn (suburban rail) (O2048) <a href="https://goo.gl/WXZ3cd">https://goo.gl/WXZ3cd</a>	2003-2004	Switzerland
N/A	Alternatives to pedestrian crossings in limited speed zones 30 km/h (SVI2004/073) <a href="https://goo.gl/2cu0Uc">https://goo.gl/2cu0Uc</a>	2008-2011	Switzerland

## 4.5 Management and governance

### 4.5.1 Introduction to the sub-theme

Infrastructure fulfils a variety of functions, including providing sufficient capacity to satisfy mobility needs; ensuring a sufficient level of comfort, safety and security; and minimising the exposure of third parties to the negative impacts of transport. These demands are addressed through the infrastructure planning, design, construction and maintenance phases. Once the infrastructure is built, apart from maintenance activities, the management and governance of transport networks ensures as good as possible compliance with the relevant performance and quality targets.

Operations management includes ensuring the availability and servicing of the infrastructure, and congestion control and mitigation within road, rail waterborne and aviation networks. The governance of interconnectivity looks across modes and network levels. It aims to ensure the physical connection of multi-level networks or geographical sub-networks within a mode and the functioning of multimodal transfer nodes for passengers and goods between the modes. Interoperability management turns the attention from infrastructure to rolling stock by managing the conditions under which trucks, trains, ships or aircraft can operate in several geographical or hierarchical networks. Resilience management looks at unusual or extreme events, and conditions and manages the return of transport networks to

normal or usable conditions. Safety management copes with the protection of users by prevention and after-treatment strategies for traffic incidents. Security management seeks to protect the transport system against willingly committed sabotage or attacks. Eventually, ITS will provide the technical infrastructure to address most of the above performance areas. However, ITS will need governance itself due to the handling of sensitive data or system-inherent risks.

The common theme of these topics is their strategic character and the common objective to provide framework conditions for the infrastructure, and its sub-systems and optimal use. 'Optimal use' refers to economic sustainability (i.e. the efficiency of infrastructure provision and operation, and environmental and social sustainability). This section presents selected research activities with high relevance to the management and governance sub-theme.

#### 4.5.1.1 Overall direction of European-funded research

As demonstrated by the significant number of projects considered for this sub-theme, the attention given to management and governance in European-funded research has steadily increased over the past decade. Situated between European and national research programmes, the research commissioned by the CEDR and ERA-NET platforms has also made substantial contributions to the topic area of management and governance.

The two topics of this section, governance and management, are widely overlapping, and in some cases, are not easy to tell apart. While 'governance' relates to a higher level and more strategic way of planning and steering transport sector activities, 'management' is more concerned with day-to-day organisation and optimisation of infrastructure conditions, demand and financing. Governance embraces the wider field of setting pricing, funding and regulatory frameworks; and setting and enforcing social rules, construction codes and safety or technical interoperability standards. Implicitly, governance touches all parts of this thematic analysis, but is most closely linked to management issues.

A core task of transport infrastructure management relates to asset management, ensuring the maintenance of the substance of transport investments over the long term, and keeping quality and availability within certain limits. Asset management strategies are usually very specific to single transport modes and types of infrastructure, and there is little research specifically related to this area. Exceptions are resilience and safety topics, where asset management serves other purposes.

Research is primarily targeted towards the TEN-T. While some research areas (e.g. resilience and security) are intermodal, others (e.g. safety and ITS) are largely focused on single modes or on specific modal connection points. A change in research direction from intelligent infrastructure, information technology (IT) systems and vehicle operations towards the management of complex passenger and freight flows is evident. New developments, such as automated driving and big data applications, are becoming visible in research programmes.

#### 4.5.1.2 Overall direction of nationally funded projects

National research on transport infrastructure management – as far as it is represented in the Transport Research and Innovation Portal (TRIP) – concentrates on road and rail networks. Road projects are concerned with the management of EVs, longer and heavier trucks, and congestion mitigation. Rail research focuses on coping with the management of capacity and safety in the network in combination with new control systems (e.g. the European Train Control System (ETCS) level 2/3). In contrast, national research in the field of waterway transport across several countries concentrates on the efficiency of terminals, ports and port clusters.

Since 2005, NRAs have agreed to share their research needs and to open up their budgets for joint research under the [ERA-NET ROAD](#) (2008–2011) programme (previously FP6 and FP7, now managed by CEDR). The topics of the programme evolved from climate adaptation (2007), safety (2009), effective asset management (2010), mobility and energy (2011) to regular calls on varying issues from 2012 onwards.

### 4.5.2 Research activities

The following sections present a selection of projects concerned with the management and governance sub-theme, which provide a snapshot of the research activities performed.

#### 4.5.2.1 Efficiency of transport operations

Research on the operation of transport infrastructure, with regard to adequacy to future challenges, tends to be mode-specific. This is not surprising as the operational challenges differ between modes and networks. The studies looked at here are closer to management issues. Nonetheless, good governance is required to allow more efficient management solutions to be implemented and to unfold successfully.

In this sense, the [TIGER](#) (2009–2012) project focused on increasing the degree of effectiveness, efficiency and competitiveness of the rail freight network. Specifically, the results of the project should serve to overcome road congestion in and around the major ports of Europe. To this end, intermodal freight logistics chains were developed and tested using four demonstrators (Genoa Fast Corridor, ports of Gioia Tauro/Taranto, ports of Hamburg/Bremerhaven and Intermodal network of Kombiverkehr GmbH). These demonstrators showed that rail intermodality, especially in combination with inland waterways, is a promising path to cope with future challenges.

Within the [2050AP+](#) (2011–2014) project, revolutionary solutions were developed to prepare airports for future demands. Specifically, airports should be designed in such a way that 90 % of European travellers could complete their journey within 4 hours. Three different airport concepts may be used to reach this goal:

- a time-efficient airport that maximises the value of time through efficient and effective transport operations;
- an airport with extremely low operating costs and high revenues;



- a green airport that is self-sustaining with regard to energy, produces low noise pollution and is climate neutral with regard to operations.

Within Horizon 2020, the [REFINET](#) (2015–2017) project aims to establish an integrated multimodal strategy, including sectors from outside the transport domain, for efficient and sustainable infrastructure management. The [FOX](#) (2015–2017) project will identify common needs and innovative techniques in the areas of construction, maintenance, inspection, and recycling and re-use of transport infrastructure. This will be across all modes and with the involvement of all key stakeholders. Governance capabilities of European transport network managers and institutions towards an integrated efficient infrastructure management are researched by the [AM4INFRA](#) (2016–2018) project.

Additionally, the operations of transport infrastructure are the focus of other research projects (e.g. [ASSET](#) (2008–2011), [INTERACTION](#) (2013–2016), [RISING](#) (2009–2012) and [CASUAL](#) (2013–2016)). The CASUAL project differs from the others in that the focus lies on the analysis of new governance systems for urban areas to ensure sustainable living and consumption patterns.

#### 4.5.2.2 Interconnectivity of transport networks

The challenge for the interconnectivity of transport networks lies in physically and operationally linking different transport systems, of either the same or different modes, to facilitate transfers between different systems. Interconnectivity necessitates the completion of missing links in each part of the physical infrastructure. Achieving interconnectivity is a necessary preliminary step towards interoperability. This challenge applies to passenger and freight transport.

Interconnectivity and interoperability constitute a strategic endeavour of European policy. Given the many implications on currently running systems, legal provisions, etc., international coordination, and thus a very careful setting of governance activities, is essential for moving towards more interconnectivity and interoperable transport systems across Europe.

Options for ensuring seamless passenger intermodality were researched by the [MODAIR](#) (2012–2014) project, which delivered a roadmap for future research. It also provided the EU with a group of experts (the European Forum on Airport Passenger Intermodality (EFAPI)) who are able to help evaluate and select the best ways of implementing the connectivity and improving the co-modality of airports with other transport modes. In addition, technological and logistical solutions to enhance intermodality were proposed, such as ticketing abilities for whole journeys or solutions for transporting luggage

Similarly, the [PLATINA](#) (2008–2012) and [PLATINA II](#) (2013–2016) projects focused on elaborating ways to accelerate the achievement of the Navigation and Inland Waterway Action and Development in Europe (NAIADES) aims – namely to enhance the use of inland waterways for intermodal freight transport. To this end, gaps in the European inland waterways infrastructure were identified and solutions to bridge these were developed. In addition, maintaining a harmonised river information system (RIS) was part of the PLATINA II project and a European expert group was established to support waterway administrations with regard to the maintenance of inland waterways.

Further research projects with a focus on freight logistics include the [NEXTRUST](#) (2015–2018), the [RETRACK](#) (2007–2012) and the [RISING](#) projects. In contrast, interconnectivity in passenger transport is the key interest of the [OPTIMISM](#) (2011–2013) and [ORIGAMI](#) (2011–2013) projects.



### 4.5.2.3 Interoperability of transport networks

Interoperability is generally defined as the ability of two or more transport systems to operate effectively and efficiently together to fulfil consumers' requirements. Achieving interoperability ensures that transport systems are not simply interconnected, but that the boundaries between different networks are effectively invisible. This enables users to undertake a 'seamless journey' between origin and destination. While the technologies for interoperable systems are available and have been in operation for some time in some sectors, careful and good governance is needed, particularly in the railway sector, to achieve higher levels of interoperability without damaging national interests or legal provisions.

In this regard, the [COST 340](#) (2002-2004) project and, more recently, the [SPIDER PLUS](#) (2012-2015) project are of note as they defined a framework of references and concepts to guide current European policy in this area. This was achieved by identifying and analysing the obstacles that transport intermodality had encountered in the past. Based on this, specifications were developed to permit interoperability through technical standardisation, commercial cooperation and interoperability between national networks.

Another project focused on interoperability was [EUROPE-TRIP](#) (1997-1999). The rail-focused research was intended to set up a business planning model to simulate strategies for infrastructure managers and policy interventions. The simulation model that was developed can be used as a tool to conduct strategic studies on European rail transport and corridors, taking particular account of the interfaces between infrastructure managers, regulatory authorities and train operators.

The interoperability of different transport systems is also the focus of the [AEROTRAIN](#) (2009-2012), [MINIMISE](#) (1996-1999), [RCI](#) (2005-2008) and [TREND](#) (2011-2014) projects. These projects focused on the interoperability between rail and other networks.

### 4.5.2.4 Transport infrastructure resilience to extreme events

Considering the growing effects of climate change (more frequent heat waves, increasing levels of precipitation and subsequent flooding, etc.), transport infrastructure is at an unprecedented risk of disruption with major repercussions on economic activities; mobility and trading patterns; and national budgets in terms of higher costs of maintenance, emergency interventions and operational costs. Enhancing the resilience of transport systems requires close cooperation between higher level governance and planning, and on-site management of preparedness, emergency management and after-treatment. The projects analysed below deal with both aspects.

The [WEATHER](#) (2009-2012) and [EWENT](#) (2009-2012) projects investigated the likely economic impacts on all modes of transport of changing weather patterns over Europe. With different focus topics, the projects investigated standard risk and impact assessment frameworks, and developed strategies for how best to prepare for changes in risk levels.

Total costs were found to range between EUR 2.5 million and EUR 20 million annually, where the largest degree of uncertainty is the level of accident costs. While some regions and transport modes might gain through warmer winters, rail transport bears the majority of costs, particularly in lower income countries, mountain areas and coastal zones. Case studies worldwide revealed that early preparation for extreme events, constant staff training and inter-company co-operation arrangements will, in most cases, be able to mitigate the very costly impacts of weather and climate impacts.

A specific view on the inland waterway sector and its sensitivity to changing weather and climate patterns was taken by the [ECCONET](#) (2010-2012) project. With time series and cross-sectional analyses of the major European inland shipping routes (i.e. the Rhine and the Danube), high waters were found to be more threatening and more likely than low waters. While the Rhine with its several sources appears more or less resilient to climate change impacts, the situation with the Danube is more sensitive. Strategies to mitigate impacts include better weather forecasts and the use of innovative vessel technologies, such as wider and shallower bodies.

Further work on the topic was performed by the [MOWE-IT](#) (2012-2014) project on multimodal resilience strategies, the [WEZARD](#) (2011-2013) and [RESILIENCE2050.EU](#) (2012-2015) projects for aviation, and the ERA-NET Road/CEDR projects [RIMAROC](#) (2008-2010) and [SWAMP](#) (2008-2010) and others on road sector risk management, governance and resilience strategies.

### 4.5.2.5 Safety

Traffic or transport safety is commonly defined as protecting users from failures of the transport system. The European vision is to halve casualties in road transport by 2020 and move towards zero fatalities by 2050 (Vision Zero) or national goals (e.g. the Austrian zero fatality vision), so the topic of traffic safety is deeply embedded in transport policy. The activities in this sub-theme are related to accident rates, the analysis of databases on road incidents and increased safety for vulnerable road users for all infrastructure (rail, maritime, roads and air along with their hubs). However, the focal point of safety research is road transport, which is particularly true for national research. There is an increasing link with the application of ITS to improve safety for all users.

The role of road infrastructure within transport safety remains a central tenet of EU research. The focus of the research was to investigate the characteristics of the road environment in causing vehicle incidents. The purpose of this was to develop a knowledge base that can provide better road design tools and strategies. In this sense, the 'transport system environment' includes technical installations; operational procedures and rules; and regulations for the infrastructure provision, operation and use. Similarly, resilience, transport safety and security involve elements of day-to-day management, and higher level and strategic governance.

The safety of transportation systems depends on various factors, including infrastructure, vehicles and regulations. For the road sector, the [ASSET-ROAD](#) (2008-2011) project analysed risk factors and options for enhancing traffic safety in the areas of driver behaviour, safe and sustainable infrastructure, traffic control and cybernetics. The concepts developed by the research combined traffic safety with efficient and sustainable asset provision and management. Pilot applications were tested in Germany, France, Finland and Austria, and were discussed at an international and trans-continental asset forum.

The goals for the [RISER](#) (2003-2006) project were to collect and analyse data on single-vehicle incidents, and to establish engineering and human factor links between the roadside infrastructure, road safety and operational issues. Among its results, this project delivered:

- accident-based analysis of roadside objects with criteria defining when these objects become hazardous to vehicle occupants;
- crash performance information for different roadside infrastructure elements identifying critical issues for selecting, installing and maintaining roadside environments;
- information identifying the influence of roadside features on the neighbouring traffic flows;
- recommendations for monitoring safety levels of roadside features.

The [SAFET](#) (2003-2006) project also targeted its research activity on the road environment, but with a specific focus on tunnel infrastructure. The goal of this project was to develop comprehensive guidelines for improving safety of existing tunnels (e.g. preventing incidents in existing tunnels and mitigating their adverse effects). Notably, the SAFET project reviewed and relied upon the findings produced by six projects funded under FP5. Among its principal results, it developed performance-based and prescriptive approaches to tunnel safety, covering a large spectrum of issues including:

- current state of practice;
- incident detection and traffic management;
- evacuation intervention management;
- post-incident investigation and evaluation;
- harmonised risk assessment;
- integrated tunnel safety management systems.

Given the importance of road safety and of technological, engineering and planning measures to increasingly mitigate and reduce the effects of road incidents, it is not surprising that national-level research has looked beyond the main risk factors to road safety. An example in this respect is the [BESIDIDO](#) (2001-2005) project. This aimed to optimise road design features and spatial planning of roads to improve road safety at an urban level. Having assessed more than 160 road safety engineering measures, the project delivered recommendations for updating relevant technical standards

and produced a handbook containing guidelines for road safety and traffic calming measures in urban areas.

Another relevant project is [PILOT4SAFETY](#) (2010-2012) that developed a manual, complemented by a collection of best practices, that could be a starting point for the development of a comprehensive tool to standardise operational procedures for the inspection and audit of secondary roads. If implemented, this would improve the level of regional road design and maintenance across Europe.

#### 4.5.2.6 Security

Securing the transport system – and its passengers, freight consignments, employees and assets – from sabotage, attacks and other threats committed by third parties is an important goal shared by transportation companies and countries all around the world. As the world ‘shrinks’ and becomes more easily accessible to all, the need to innovate and update security measures to ensure the safety of all people in public spaces and that passengers can move safely from point A to B increases just as rapidly. Studies on transport system security are researching the latest technological methods that will result in autonomous measures, such as invisible screening of dangerous objects (e.g. the [ATOM](#) (2009-2012) project) and robust structural designs (e.g. the [SECURESTATION](#) (2011-2014) project). This research includes technology application and on-site emergency management. However, governance issues, in particular legal provisions, get less attention in the projects reviewed. The research supports the prevention, reduction (of impact) and safer evacuation of people in various public spaces (e.g. trains, stations, ferries, cruise vessels, ports and airports) in response to serious threats by physical or cyber attacks (e.g. the [SECTRONIC](#) (2008-2011), [EMAR](#) (2012-2014) and [ASPIS](#) (2008-2011) projects).

The [GETAWAY](#) (2011-2014) project started from the observation that people need help during severe catastrophic events to get directions to secure exits and that firefighters cannot be present at all critical locations for assistance. Research has shown that, under emergency conditions, only 38 % of people take notice of emergency signage. To improve the usefulness of such signs, the GETAWAY project developed novel and smarter emergency signage to prevent the loss of lives in overground and underground stations and terminals. The project developed a new active intelligent system of signs without altering the size of existing signage. The main features of the novel system can be summarised as follows:

- effectively able to evacuate large crowds from underground stations;
- over 100 % higher visibility, allowing people to make faster decisions;
- over 90 % accuracy in counting people using new imaging analyses.

The [SECTRONIC](#) project addressed surveillance and the ultimate protection of critical maritime infrastructure against damage, deliberate destruction, national catastrophes, accidents, computer hacking, criminal activity and malicious behaviour.

It considered passenger and goods transport, energy supply and port infrastructure. The concept followed by the project was to link all accessible means of observation (i.e. offshore, onshore, air and space) via an onshore control centre.

The project resulted in the development and launching of a new and revolutionary 'command and control security system'. The features of the system include:

- creating an intuitive 360° situational awareness picture around an infrastructure by tracking, classifying and deterring potentially threatening objects;
- automatically activating alarms and warnings by surface loudhailers and laser dazzler;
- providing critical information and live video of the suspicious target to enable users to make the right decisions under time pressure.

Based on its modular architecture, the system is fully scalable to meet the security needs of coastal infrastructure (e.g. ports, power plants and naval bases), offshore assets (e.g. rigs, ships and yachts), and wide area land and border protection. Since 2011, the system's track record includes the protection of heads of states and the 2012 Olympic Games.

#### 4.5.2.7 ITS supporting transport infrastructure governance

The efficient governance of transport infrastructure requires a high level of embedded intelligence in the infrastructure and systems to support the decision-making process for the operators, managers and owners of transport infrastructure. Such systems can also facilitate the appropriate deployment

and use of the infrastructure by enabling advanced end-user applications in transport services and operations.

With regard to the rail network, the [EATS](#) (2012–2016) project focused on supporting the rollout of the ETCS. This is based on an improvement of the testing laboratory and provides an acceleration of the testing process. The project also developed a blueprint for a satellite positioning system (Smart Train Position System (STPS)).

Road traffic could also profit immensely from advanced information and communication systems. Various projects focus on this topic. One example is the [COLOMBO](#) (2012–2015) project, which aimed to develop a self-organising system for low carbon mobility at low penetration rates of cooperative systems. Within this system, information on the traffic flow is obtained from car-to-car and car-to-infrastructure communication and is used for traffic-light control based on swarm intelligence.

To solve the partly conflicting objectives of enhancing sustainability, reliability and comfort, while reducing costs of transport infrastructure systems, the [USE-IT](#) (2015–2017) project explores options to make best use of novel IT technologies. With regards to new developments in electronic ticketing, sensor technology, mobile communication and big data, the project will explore challenges, solutions and future research needs for road and rail networks. The USE-IT project is closely linked to the [FOR](#) (2011–2016) roadmapping project of the FEHRL. Together with the three sister activities for rail, shipping and aviation, FEHRL has presented detailed roadmaps for each mode within the [FORx4](#) initiative.



Other projects highlighting the potential of ITS with regard to air traffic include the [AIRTN-NEXTGEN](#) (2013-2015), [LEONARDO](#) (2000-2004) and [SANDRA](#) (2009-2013) projects. Multimodal considerations are included as part of the [GALILEAN](#) (2001-2004), [STADIUM](#) (2009-2013) and [UNIACCESS](#) (2005-2006) projects.

### 4.5.3 Research outcomes

#### 4.5.3.1 Achievements of the research under this sub-theme

The review of studies has shown an increasing interest in using ITS technologies for managing and securing transport infrastructure. The applications range from the surveillance of network conditions through the improvement of transport flows to safeguarding passengers, goods and assets. As part of the projects reviewed, integrated safety and control systems have been developed within individual transport modes and across modes. Within single modes, applications for the European Rail Traffic Management System (ERTMS), air traffic management (ATM) within the Single European Sky ATM Research (SESAR) programme and road management systems are targets for improvement and efficiency gains. In particular, the generation of critical data through intelligent crowd sourcing and the application of big data methods advanced the functionality and usability of such systems to a large extent.

ITS may have an active role to play in improving efficiency and, most importantly, the safety of drivers, vulnerable road users and businesses. It supports the understanding that cooperative communication and a good level of data processing is necessary to deliver information in real time. Moreover, ITS applications may be helpful in promoting transport modes, other than road, for freight transportation, making them more competitive and a realistic alternative.

Intermodal solutions are driven by smart phone apps and collaboration between different parties in cities. Only through powerful trans-modal traffic management, routing and booking systems is contemporary mobility behaviour possible. The Galileo global satellite navigation system, which will be available in the near future, will provide another platform for developing new services and products. The full value of Galileo for transport infrastructure and governance is still to be unveiled, but research and development projects are good ways of doing so.

#### 4.5.3.2 Transferability from research into practical use

In terms of management and governance, European and national projects have shed light on the decision structures, on the interdependencies within specific modes and between the transport modes. In many instances (e.g. intelligent roads and train control systems), the interrelationship between management and governance systems and new technology developments have been demonstrated. Management and governance systems are not independent of each other and have to be considered and implemented jointly. In particular, the development of research activities shows how quickly the

philosophy and the achievable objectives of infrastructure management can – and must – change to adapt to new conditions.

The continuity of projects is needed to arrive at the practical stage, especially taking into account the fact that technology is evolving very quickly and that, in many cases, it is based on different standards of ITS.

#### 4.5.3.3 Indications for future research

As indicated above, future research, in terms of the management and governance of transport infrastructure systems, must be able to adapt to new technology options and changing social trends. Next-generation mobile communication technologies and big-data applications have to be connected to traditional management structures to support long-life transportation infrastructure.

Strategic governance issues (i.e. planning, decision support and legal provisions) need to be developed and/or updated to keep pace with these rapid developments. This is because most of the infrastructure that is built today will still be in place in 50 years to 100 years. There is a need to maintain flexibility and sustainability of planning systems from current predict-and-provide systems to plan-and-manage approaches across several regional entities, countries and modes of transport. Other topics, less related to road transport, should be further developed along with themes related to the multimodality and efficiency of transport logistics. A transfer of sustainable urban mobility planning (SUMP) to national and European planning frameworks is recommended.

Out of these, legal aspects in infrastructure planning could gain more weight. Since more and more user data are available to predict infrastructure conditions, and users demand more detailed data on infrastructure and network conditions, privacy issues come into play. However, common standards and directives should still be developed.

#### 4.5.3.4 Implications for future policy development

Since 2010, the European Commission has been committed to introducing an EU-wide strategic target to reduce serious road traffic injuries, and the same applies to rail and other modes of transport. Research must be linked to implementation. It does not mean that research-oriented projects should not be funded, but there is a desire to ensure that their results remain applicable to real-world situations. It also means that there should be a link with standards, directives and regulations to update or modify them accordingly.

ITS technologies are evolving very rapidly, some current projects may already be outdated. Therefore, it is important to give continuity to projects to take advantage of previous knowledge and avoid transferability gaps.

### 4.5.4 List of projects

Table 4-5 lists the more significant projects included in the review of this sub-theme.



Table 4-5 Projects reviewed in the management and governance sub-theme

Project acronym	Project name	Project duration	Source of funding
2050AP+	The 2050+ Airport <a href="https://goo.gl/HwaK8l">https://goo.gl/HwaK8l</a>	2011-2014	EU (FP7-TPT)
AEROTRAIN	AEROdynamics Total Regulatory Acceptance for the Interoperable Network <a href="https://goo.gl/yhuP1H">https://goo.gl/yhuP1H</a>	2009-2012	EU (FP7-SST)
AIRTN-NEXTGEN	Air Transport Network – Next Generation <a href="https://goo.gl/isv09s">https://goo.gl/isv09s</a>	2013-2015	EU (FP7-TPT)
AM4INFRA	Common Framework for a European Life Cycle based Asset Management Approach for transport infrastructure networks <a href="https://goo.gl/FI8sSX">https://goo.gl/FI8sSX</a>	2016-2018	EU (Horizon 2020)
ASPIs	Autonomous Surveillance in Public transport Infrastructure Systems <a href="https://goo.gl/sMzacu">https://goo.gl/sMzacu</a>	2008-2011	EU (FP7-SST)
ASSET	ASSET – Aeronautic Study on Seamless Transport <a href="https://goo.gl/1ISQhq">https://goo.gl/1ISQhq</a>	2008-2011	EU (FP6-INTEGRATING)
ASSET-ROAD	ASSET Advanced Safety and Driver Support in Essential Road Transport <a href="https://goo.gl/tC8Ht3">https://goo.gl/tC8Ht3</a>	2008-2011	EU (FP7-TPT)
ATOM	Provision of Access to Transport Models <a href="https://goo.gl/utj3Et">https://goo.gl/utj3Et</a>	2009-2012	EU (FP5-GROWTH)
CASUAL	Co-creating Attractive and Sustainable Urban Areas and Lifestyle – Exploring new forms of inclusive urban governance <a href="https://goo.gl/8skUVU">https://goo.gl/8skUVU</a>	2013-2016	Netherlands
COLOMBO	Cooperative Self-Organizing System for low Carbon Mobility at low Penetration Rates <a href="https://goo.gl/sBQbdl">https://goo.gl/sBQbdl</a>	2012-2015	EU (FP7-ICT)
COST 340	Towards a European intermodal transport network: lessons from History <a href="https://goo.gl/fQnT2H">https://goo.gl/fQnT2H</a>	2002-2004	EU (COST)
EATS	ETCS Advanced Testing and Smart Train Positioning System <a href="https://goo.gl/WMpOG4">https://goo.gl/WMpOG4</a>	2012-2016	EU (FP7-TPT)
ECCONET	Effects of Climate Change On the inland waterway and other transport NETworks <a href="https://goo.gl/qCijjC">https://goo.gl/qCijjC</a>	2010-2012	EU (FP7-TPT)
EMAR	e-Maritime Strategic Framework and Simulation based Validation <a href="https://goo.gl/z2C5jH">https://goo.gl/z2C5jH</a>	2012-2014	EU (FP7-TPT)
EUROPE-TRIP	European Railways Optimisation Planning Environment – Transportation Railways Integrated Planning <a href="https://goo.gl/qrI05i">https://goo.gl/qrI05i</a>	1997-1999	EU (FP4)
EWENT	Extreme Weather impacts on European Networks of Transport <a href="https://goo.gl/NT1yjO">https://goo.gl/NT1yjO</a>	2009-2012	EU (FP7-TPT)
FOR	Forever Open Road <a href="https://goo.gl/V86Plv">https://goo.gl/V86Plv</a>	2011-2016	International
FOX	Forever Open infrastructure across (X) all transport modes <a href="https://goo.gl/qKMxEN">https://goo.gl/qKMxEN</a>	2015-2017	EU (Horizon 2020)
GALILEAN	Galileo Application Network <a href="https://goo.gl/uXgESc">https://goo.gl/uXgESc</a>	2001-2004	EU (FP5-IST)

Table 4-5 (continued) Projects reviewed in the management and governance sub-theme

Project acronym	Project name	Project duration	Source of funding
GETAWAY	Generating simulations to Enable Testing of Alternative routes to improve WAYfinding in evacuation of overground and underground terminals <a href="https://goo.gl/l8Y0vq">https://goo.gl/l8Y0vq</a>	2011-2014	EU (FP7-TPT)
INTERACTION	Innovative Technologies and Researches for a new Airport Concept towards Turnaround coordination <a href="https://goo.gl/uX4l6E">https://goo.gl/uX4l6E</a>	2013-2016	EU (FP7-TPT)
LEONARDO	Linking Existing on Ground, Arrival and Departure Operations <a href="https://goo.gl/MRMuvd">https://goo.gl/MRMuvd</a>	2000-2004	EU (FP5-GROWTH)
MINIMISE	Managing Interoperability by Improvements in Transport System Organisation in Europe <a href="https://goo.gl/4VtniR">https://goo.gl/4VtniR</a>	1996-1999	EU (FP4)
MODAIR	Co-modal Airport <a href="https://goo.gl/FNktFU">https://goo.gl/FNktFU</a>	2012-2014	EU (FP7-TPT)
MOWE-IT	Management of weather events in transport system <a href="https://goo.gl/Xxd6EJ">https://goo.gl/Xxd6EJ</a>	2012-2014	EU (FP7-TPT)
NEXTRUST	Building sustainable logistics through trusted collaborative networks across the entire supply chain <a href="https://goo.gl/BDJvOz">https://goo.gl/BDJvOz</a>	2015-2018	EU (Horizon 2020)
OPTIMISM	Optimising Passenger Transport Information to Materialize Insights for Sustainable Mobility <a href="https://goo.gl/a8yC1m">https://goo.gl/a8yC1m</a>	2011-2013	EU (FP7-TPT)
ORIGAMI	Optimal Regulation and Infrastructure for Ground, Air and Maritime Interfaces <a href="https://goo.gl/Fmha1J">https://goo.gl/Fmha1J</a>	2011-2013	EU (FP7-TPT)
PILOT4SAFETY	Pilot project for common EU Curriculum for Road Safety experts <a href="https://goo.gl/nV3Shi">https://goo.gl/nV3Shi</a>	2010-2012	EU (FP4)
PLATINA	Platform for the implementation of NAIADES <a href="https://goo.gl/cTTu4a">https://goo.gl/cTTu4a</a>	2008-2012	EU (FP7-TPT)
PLATINA II	Platform for the implementation of NAIADES (PLATINA II) <a href="https://goo.gl/ivePvx">https://goo.gl/ivePvx</a>	2013-2016	EU (FP7-TPT)
RCI	Road charging interoperability pilot project <a href="https://goo.gl/OOPDOR">https://goo.gl/OOPDOR</a>	2005-2008	EU (FP6-SUSTDEV)
REFINET	REthinking Future Infrastructure NETworks <a href="https://goo.gl/KKQNFQ">https://goo.gl/KKQNFQ</a>	2015-2017	EU (Horizon 2020)
RESILIENCE2050.EU	New design principles fostering safety, agility and resilience for ATM <a href="https://goo.gl/lshMY4">https://goo.gl/lshMY4</a>	2012-2015	EU (FP7-TPT)
RETRACK	Reorganisation of Transport Networks by Advanced Rail Freight Concepts <a href="https://goo.gl/33VUJ3">https://goo.gl/33VUJ3</a>	2007-2012	EU (FP6-SUSTDEV)
RIMAROCC	Risk Management for Roads in a Changing Climate <a href="https://goo.gl/HQCDOG">https://goo.gl/HQCDOG</a>	2008-2010	EU (ERA-NET)
RISER	Roadside Infrastructure for Safer European Roads <a href="https://goo.gl/ZREIWv">https://goo.gl/ZREIWv</a>	2003-2006	EU (FP5-GROWTH)
RISING	RIS services for improving the integration of inland waterway transports into intermodal chains <a href="https://goo.gl/gyl6pK">https://goo.gl/gyl6pK</a>	2009-2012	EU (FP7-SST)

Table 4-5 (continued) Projects reviewed in the management and governance sub-theme

Project acronym	Project name	Project duration	Source of funding
SAFET	Safety in tunnels Thematic Network <a href="https://goo.gl/CLVQjs">https://goo.gl/CLVQjs</a>	2003-2006	EU (FP5-GROWTH)
SANDRA	Seamless Aeronautical Networking through Integration of Data Links, Radios, and Antennas <a href="https://goo.gl/MzHsfv">https://goo.gl/MzHsfv</a>	2009-2013	EU (FP7-TPT)
SECTRONIC	Security System for Maritime Infrastructures, Ports and Coastal Zones <a href="https://goo.gl/FNeYck">https://goo.gl/FNeYck</a>	2008-2011	EU (FP7-SEC)
SECURESTATION	Passenger station and terminal design for safety, security and resilience to terrorist attack <a href="https://goo.gl/n8DDtG">https://goo.gl/n8DDtG</a>	2011-2014	EU (FP7-SST)
SPIDER PLUS	Sustainable Plan for Integrated Development through the European Rail Network Projecting Logistics & Mobility for Urban Spatial Design Evolution <a href="https://goo.gl/SPn00k">https://goo.gl/SPn00k</a>	2012-2015	EU (FP7-TPT)
STADIUM	Smart Transport Applications Designed for Large Events with Impacts on Urban Mobility <a href="https://goo.gl/cozRsO">https://goo.gl/cozRsO</a>	2009-2013	EU (FP7-TPT)
SWAMP	Storm Water prevention -Methods to Predict damage from the water stream in and near road pavements in lowland areas <a href="https://goo.gl/W7jX34">https://goo.gl/W7jX34</a>	2008-2010	EU (ERA-NET)
TIGER	Transit via Innovative Gateway concepts solving European-Intermodal Rail needs <a href="https://goo.gl/Trwi6c">https://goo.gl/Trwi6c</a>	2009-2012	EU (FP7-SST)
TREND	Test of Rolling Stock Electromagnetic Compatibility for cross-Domain interoperability <a href="https://goo.gl/S63znK">https://goo.gl/S63znK</a>	2011-2014	EU (FP7-TPT)
UNIACCESS	Design of Universal Accessibility Systems for Public Transport <a href="https://goo.gl/AUZYw5">https://goo.gl/AUZYw5</a>	2005-2006	EU (FP6-SUSTDEV)
USE-IT	Users, Safety, security and Energy In Transport Infrastructure <a href="https://goo.gl/UETJrb">https://goo.gl/UETJrb</a>	2015-2017	EU (Horizon 2020)
WEATHER	Weather Extremes: Assessment of impacts on Transport Systems and Hazards for European Regions <a href="https://goo.gl/clcn0q">https://goo.gl/clcn0q</a>	2009-2012	EU (FP4)
WEZARD	Weather hazards for aeronautics <a href="https://goo.gl/pCH064">https://goo.gl/pCH064</a>	2011-2013	EU (FP7-TPT)
BESIDIDO	Research into improving road traffic safety by means of transport engineering and organisational monitoring <a href="https://goo.gl/dQQfJU">https://goo.gl/dQQfJU</a>	2001-2005	Czech Republic

## 4.6 Monitoring and maintenance

### 4.6.1 Introduction to the sub-theme

Reliable transport infrastructure is crucial to the smooth functioning of transport system and for Europe's economic and social development. Inevitably, the intensive use of infrastructure leads to deterioration and damage, which necessitates maintenance throughout its life-cycle. Maintenance requires extensive planning to ensure that repairs are carried out safely, while limiting the disruption for users; minimise the economic impacts of delays and congestion; and avoid unnecessary impacts on the local environment.

To help this process, monitoring transport infrastructure can deliver important information on the status of existing infrastructure and inform network managers of the need for repair. As demonstrated by the research projects assessed in this sub-theme, effective infrastructure management and the application of sustainable development principles, can help to find an optimal compromise between economic repairs and a more sustainable transport infrastructure. A full list of projects that were reviewed is shown in Table 4-6.

#### 4.6.1.1 Overall direction of European-funded research

The projects categorised into this sub-theme span the period from 1996 to 2016 and were funded through a range of programmes such as FP7 and Horizon 2020. During this period, the majority of European-level projects concentrated on rail or road transport, although a number of other transport modes, such as air and water, were covered.

The emphasis on research into road and rail infrastructure will further the development of the TEN-T core network and facilitate smoother cross-border transport. These are key goals of the EU's transport infrastructure policy. Other recent trends in European-level research within the monitoring and maintenance sub-theme are discussed in the following sections<sup>23</sup>.

#### 4.6.1.2 Overall direction of nationally funded projects

At a European level, there is a strong focus on road and rail transport, but projects at a national level have mainly focused on road transport. Some projects also explored transport interfaces and terminals, which indicates that improving intermodality is also a priority. Compared with European projects, relatively little information was available in TRIP on national projects.

### 4.6.2 Research activities

Besides the overall emphasis on road and rail infrastructure, several other key topics were identified within the area of monitoring and maintenance research. Sections 4.6.2.1 and 4.6.2.2 discuss the areas that have been explored the most extensively. Recent project examples are provided to showcase some of the research that has taken place in Europe and to give further insight into the latest trends within this sub-theme. To highlight the diversity of ongoing research in Europe, the project examples that have been selected are intended to cover a wide range of applications and transport modes,

#### 4.6.2.1 Monitoring

Frequent and precise monitoring of transport infrastructure is necessary to identify future maintenance needs and to detect hazardous situations. Monitoring infrastructure during maintenance works can also provide useful data on the impacts of maintenance and can be used to limit the economic impacts of disruption when future works are being planned. Two key topic areas were identified within the area of infrastructure monitoring research:

- sensors and detection technologies to detect deterioration and damage to infrastructure;
- enhanced computing/data capabilities, using ITS and developing more advanced models to predict maintenance needs.

#### 4.6.2.1.1 Sensors and detection technologies

The real-time monitoring of infrastructure is becoming increasingly common for some applications. This can be achieved via the use of sensing technologies and advanced data processing capabilities. Ultimately, early detection of infrastructure deterioration can help to understand maintenance needs and lead to increased safety. The use of sensing technologies has been explored for rail, road/pavements and other types of infrastructure (e.g. bridges).

Within rail transport, the [QUIET-TRACK](#) (2013-2016) project monitored the noise from tracks to aid the development of track-based noise mitigation systems and preventive maintenance schemes. On-board monitoring systems were used to measure the roughness of the track and to establish relationships between rolling noise and different types of rail wear. These data could then be used to construct city noise maps (as required by the European Noise Directive) and to identify precise locations where improvements are required. A number of preventive maintenance solutions were then developed and tested. Overall, these are expected to achieve a noise reduction performance of at least 6 dB (A) in comparison with the global rolling noise measured on a well-maintained standard track.

The [INTERAIL](#) (2009-2012) project also explored track inspection technology. This project approached monitoring from a safety perspective, as a large proportion of incidents related to rail infrastructure (such as derailments) are caused by the failure of a section of the line. The project had the ambitious aim of eliminating rail failures via the development and implementation of an integrated high-speed system for the reliable inspection of rail tracks. The sensing system combined three non-destructive evaluation technologies (alternating current field measurement (ACFM), ultrasonics and automated vision) in a single device. The results showed improvements in operational cost efficiency and reliability.

Other projects in this area include the [SAFE-RAIL](#) (2004-2008), [CATIEMON](#) (2005-2009) and [PMnIDEA](#) (2009-2012) projects. The SAFE-RAIL project successfully implemented novel trackside systems for inspecting wheels and axles of moving trains. The CATIEMON project researched techniques to monitor the condition of overhead line equipment. The PMnIDEA project developed novel inspection and sensor technologies for rail/tram track infrastructure.

Projects assessing sensors and detection technologies were also evident within road transport and other types of infrastructure such as bridges. For example, the [RPB HealTec](#) (2014-2016) project aimed to improve road safety by optimising the inspection and maintenance of European roads. An automated non-destructive technique for high-speed road analysis was developed to detect the presence of defects and assess the cause, extent and rate of deterioration. This system consists of three technologies (ground penetrating radiography, infrared thermography and air-coupled ultrasonic testing) and

<sup>23</sup> The identification of current research trends within this sub-theme analysis is mainly based on projects finishing from 2010 onwards.



is capable of providing analysis in real time without disturbance to traffic.

Research in the area of sensors has also been carried out in the [SENSKIN](#) (2015-2018) and [TRIMM](#) (2011-2014) projects. SENSKIN, a recently funded project, is carrying out cutting-edge research on sensors for the structural monitoring of elements of transport infrastructure such as bridges. It aims to use spatial sensing techniques to measure strains in the range of 0.012 % to over 10 %. Current structural health monitoring sensors rely on expensive, point-sensors that cannot measure strains higher than about 2 %. The SENSKIN project aims to achieve this ambitious goal by developing a dielectric-elastomer and micro-electronics-based sensing solution. The TRIMM project addressed the research topic from an asset management perspective and investigated how data generated by the range of available sensing technologies could be valuable to network managers. Methods to process and interpret data efficiently were investigated, while improved road and bridge sensors were also developed and evaluated (including vehicle-based sensors). These tools had the capability to monitor infrastructure in real time to detect early damage and to suggest optimal maintenance methods.

#### 4.6.2.1.2 Enhanced computing capabilities, modelling and ITS

The increased use of data, computing, ITS and the development of more complex modelling strategies has also attracted substantial attention in infrastructure monitoring research. One of the main benefits of research in this area has been the development of more advanced models capable of predicting maintenance needs. This brings a level of automation to the monitoring and maintenance of transport infrastructure and has the potential to reduce maintenance-related disruption. This trend has been observed in projects related to several transport modes. For example, the focus of the [INFRALEERT](#) (2015-2018) project is road and rail infrastructure. It aims to develop an expert-based information system to automate infrastructure management. This includes the collection, storage and analysis of infrastructure inspection data. The system will be built using artificial intelligence techniques and a cloud-based framework will be used for the management system.

The [OPTIRAIL](#) (2012-2015) project developed tools based on fuzzy logic and computational intelligence techniques to manage all elements of track maintenance along European railway corridors. Based on information stored in monitoring systems, the future maintenance needs of the infrastructure can be predicted with an optimal allocation of resources. Another project that developed a model for rail infrastructure maintenance requirements was the '[Link and Effect Model](#)' (2010-2013) project. This project developed a model to improve railway performance measurement systems. It mapped maintenance activities and developed monitoring methods for reliability, availability, maintainability and safety. Algorithms for data analysis and simulation were also used to support decision making.

The [MAINLINE](#) (2011-2014) project was also related to monitoring and maintenance of rail infrastructure. Degradation models, and monitoring and evaluation techniques were investigated and used as an input to a life-cycle asset management tool developed in the project. The tool was designed to inform decision makers about the environmental and economic effectiveness of different maintenance options.

Projects related to other transport modes were [MOBI-ROMA](#) (2011-2013), which focused on road infrastructure, and [HTA](#) (2006-2011), which focused on maritime infrastructure. The MOBI-ROMA project evaluated road condition and performance assessment techniques based on satellite navigation systems. These monitoring systems used floating car data from intelligent cars' sensors. Data were communicated from the cars to a central database for analysis and further processing. The HTA project set up a European Network of Excellence (NoE) and carried out testing of hydrodynamic models for offshore structures and ships. A key part of the project involved knowledge sharing about novel measurement and analysis techniques.

#### 4.6.2.2 Maintenance

Maintenance is vital over the life-cycle of infrastructure to ensure that it continues to function safely and efficiently, and to ensure that deterioration is repaired. Over the life-cycle of an asset, this is often a costly process and may cause disruption to end-users, leading to social and economic impacts. Efficient maintenance can have numerous other advantages. For example, it may be possible to increase the capacity or extend the life of existing infrastructure, meaning that costly new structures do not need to be constructed. Therefore, research in this area focuses heavily on searching for novel, cost-effective solutions that have the potential to increase efficiency and reduce downtime. Two key topics were identified:

- automation and smart maintenance of infrastructure;
- development of state-of-the-art maintenance decision-support strategies.



#### 4.6.2.2.1 Automation and smart maintenance of infrastructure

While research on this topic was performed for various types of infrastructure, the trend was particularly evident within rail. Projects of particular significance in this area include [ACEM RAIL](#) (2010–2013), [AUTOMAIN](#) (2011–2014) and [SMART RAIL](#) (2011–2014).

The ACEM RAIL project focused on optimising the maintenance of railway tracks. During the project, new technologies were trialled for the automated inspection of tracks, predictive algorithms were developed to estimate maintenance needs, and models and tools were developed to monitor whether maintenance had been carried out correctly.

The main benefits reported were a reduction in costs; lower impact on rail services; and an increase in safety, quality and reliability.

The objective of the AUTOMAIN project was to improve the service for freight rail services on the existing network. Automation was introduced to increase the reliability, availability, maintainability and safety of services, and to reduce downtime. Best practice in maintenance from other industries (such as highways and aerospace) was also adopted and a maintenance planning and scheduling tool was developed.

The main goal of the SMART RAIL project was to reduce replacement costs and delay, and to develop maintenance solutions for ageing infrastructure that have less impact on the environment. An automatic sensor system to prioritise maintenance and a life-cycle analysis tool were developed.

#### 4.6.2.2.2 State-of-the-art strategies for maintenance

A number of projects developed guidance or produced decision-support models for improved maintenance strategies. They included European-funded projects (e.g. the [PLATINA II](#) (2013–2016), [FOX](#) (2015–2017), [USE-IT](#) (2015–2017), [DESTINATIONRAIL](#) (2015–2018), [CEREAL](#) (2011–2013), [ROADAPT](#) (2013–2015) and [SABARIS](#) (2010–2012) projects) and nationally funded projects (e.g. the Czech Republic's [Information system for decision-making support in the area of road transport safety](#) (20014–2008) project). The majority of these projects developed infrastructure-management tools based on monitoring and maintenance information. Predictive modelling and real-time analyses were also used to prevent unnecessary maintenance decisions, while the creation of knowledge-sharing networks helped support infrastructure asset managers. This topic area has a large overlap with the infrastructure management sub-theme, so is not discussed in further detail in this section.

### 4.6.3 Research outcomes

#### 4.6.3.1 Achievements of the research under this sub-theme

The projects analysed in this sub-theme have shown that a large amount of research is being carried out to modernise the methods used to monitor and maintain Europe's transport

infrastructure. In all transport modes, cost-effective solutions are being sought to deliver long-lasting improvements to infrastructure and to limit the costly disruption caused by repair works. Research is also beginning to have a greater environmental focus, as exemplified by the [SUREBRIDGE](#) (2015–2018) and [QUIET-TRACK](#) projects. For example, through monitoring railway track wear/performance and implementing solutions, QUIET-TRACK was able to successfully meet its objective to deliver noise reductions of 6 dB (A) compared with contemporary technologies.

Significant results were also achieved in other areas. As demonstrated by projects with a monitoring emphasis, more advanced infrastructure monitoring technologies are becoming possible, alongside predictive techniques that will support maintenance decisions. Sensing technologies are also increasingly being tested for the detection of deterioration in real time. This can result in earlier detection of damage, more timely repairs and promote a safer transport network. Specifically, the [INTERAIL](#) project developed an automated inspection system that was shown to produce reliable results for detecting rail damage. According to the final project report, there is now good potential for commercialisation of the prototype device.

Further research projects focused on novel materials for the maintenance of other types of infrastructure. One example is the [CO-PATCH](#) (2010–2012) project, which investigated the use of composite materials to reinforce or repair large steel infrastructure (e.g. bridges and ships). The composite material patching used in the project was found to significantly reduce the maintenance costs for steel structures.

#### 4.6.3.2 Transferability from research to practical use

The step from research to practical use is a significant milestone for researchers and, inevitably, is not always achieved. However, within this sub-theme, several promising examples were identified and so were the factors that may have contributed to this success.

The area of monitoring, in particular, lends itself to potential rapid dissemination and exploitation, as much of the sensing technologies developed do not need to be embedded in the infrastructure itself. The [INTERAIL](#) and [CATIEMON](#) projects have developed technologies that are ready for exploitation. On the maintenance aspects, the exploitation route may be longer as there is a greater requirement to embed the technology in the infrastructure. The [CO-PATCH](#) project provides an example of a technology development that is well-placed for practical exploitation.

In each of these examples, a key feature of the project is the wide range of organisations involved (including industry representatives) that are able to provide a route for the exploitation of the technology. The adoption of such a collaborative approach to research projects could contribute to a successful exploitation of the results from future projects.

#### 4.6.3.3 Indications for future research

The research projects assessed in this sub-theme covered all of the major transport modes, although road and rail transport were especially well researched. Based on an assessment of the projects in this review, it is thought that further work could be carried out in areas relevant to air and water transport. It may also be beneficial to carry out further research into intermodal transport terminals as this is being promoted by EU policy.

Within the maintenance topic, developments in materials science are showing potential. However, further work could still be carried out to provide solutions that are more sustainable. Recycling of materials is starting to receive attention in road infrastructure. This suggests that, in the future, there may be a place for a circular-economy-style strategy in the transport infrastructure sector.

Finally, there are many fewer national projects than EU-funded projects in this area and less information is readily available on these projects. However, this may just be an indication that national projects would benefit from an improved sharing of results within Europe, rather than an indication of a lack of research at a national level.

#### 4.6.3.4 Implications for future policy development

As research is often a costly process, progress needs to be monitored regularly. Overall, the projects assessed in this sub-theme review show an excellent fit with EU policy goals and support the continued development of the TEN-T network. Regular assessments should continue to be made to ensure the fit with policy objectives is maintained and to identify areas that require further research.

Another point to note is the importance of building on previous research. Therefore, the development of mechanisms to support follow-on funding for successful projects may be useful and could help to accelerate the path from research to commercialisation. In this respect, initiatives such as [ERA-NET ROAD](#) (2008-2011), [ERA-NET ROAD II](#) (2009-2011) and [INFRAVATION](#) (2014-2018) appear to have been valuable due to their ability to attract funding and partnerships with other organisations<sup>24</sup>.

#### 4.6.4 List of projects

Table 4-6 lists the more significant projects included in the review of this sub-theme.

**Table 4-6 Projects reviewed in the monitoring and maintenance sub-theme**

Project acronym	Project name	Project duration	Source of funding
EU-funded projects			
ACEM RAIL	Automated and cost effective maintenance for railway <a href="https://goo.gl/chY4oQ">https://goo.gl/chY4oQ</a>	2010-2013	EU (FP7-TPT)
AUTOMAIN	Augmented Usage of Track by Optimisation of Maintenance, Allocation and Inspection of railway Networks <a href="https://goo.gl/njJLEx">https://goo.gl/njJLEx</a>	2011-2014	EU (FP7-TPT)
CATIEMON	Catenary Interface Monitoring Coherent sensing technology for electrical railway infrastructure and rolling stock for interoperable cross boundary transportation <a href="https://goo.gl/8U5CMr">https://goo.gl/8U5CMr</a>	2005-2009	EU (FP6-SUSTDEV)
CO-PATCH	Composite patch repair for marine and civil engineering infrastructure applications <a href="https://goo.gl/B54ANM">https://goo.gl/B54ANM</a>	2010-2012	EU (FP7-TPT)
DESTinationRAIL	Decision Support Tool for Rail Infrastructure Managers <a href="https://goo.gl/C2HFmq">https://goo.gl/C2HFmq</a>	2015-2018	EU (Horizon 2020)
ERA-NET ROAD	Sub projects considered in this analysis: <ul style="list-style-type: none"> <li>• IRDES: Improving Roadside Design to Forgive Human Errors</li> <li>• IRWIN: Improved local Winter Index to assess Maintenance Needs and Adaptation Costs in Climate Change Scenarios</li> <li>• P2R2C2: Pavement Performance and Remediation Requirements following Climate Change</li> <li>• RIMAROCC: Risk Management for Roads in a Changing Climate</li> </ul> <a href="https://goo.gl/6EgNzU">https://goo.gl/6EgNzU</a>	2008-2011	EU (CEDR)

<sup>24</sup> The ERA-NET scheme was set up to increase the cooperation and coordination of research activities carried out at national or regional level in the Member States and Associated States through the networking of research activities, including their 'mutual opening' and the development and implementation of joint activities. A number of joint programmes were established (such as ROAD), which funded a series of projects.

Table 4-6 (continued) Projects reviewed in the monitoring and maintenance sub-theme

Project acronym	Project name	Project duration	Source of funding
EU-funded projects			
ERA-NET ROAD II	Sub projects considered in this analysis: <ul style="list-style-type: none"> <li>• CEREAL – CO<sub>2</sub> Emission Reduction in roAd Lifecycles</li> <li>• InterMat4PMS – Integration of Material-science based Performance Models into Life-cycle Analysis processed in the Frame of PMS</li> <li>• MOBI-ROMA – Mobile Observation Methods for Road Maintenance Assessments</li> <li>• POTHOLE – Durable Pothole Repairs</li> <li>• RECYPMA – Possibilities for high Quality Recycling of Polymer modified Asphalt</li> <li>• SABARIS: Stakeholder Benefits and Road Intervention Strategies</li> <li>• STARs – Scoring Traffic at Roadworks</li> <li>• TOOLBOX – A Method to select Maintenance Candidates</li> </ul> <a href="https://goo.gl/mhfEsu">https://goo.gl/mhfEsu</a>	2009-2011	EU (FP7-TPT)
FOX	Forever Open infrastructure across (X) all transport modes <a href="https://goo.gl/qKMXeN">https://goo.gl/qKMXeN</a>	2015-2017	EU (Horizon 2020)
HP FUTURE-BRIDGE	High performance (Cost Competitive, long-life and low maintenance) composite bridges for rapid infrastructure renewal <a href="https://goo.gl/524IMV">https://goo.gl/524IMV</a>	2006-2009	EU (FP6-SUSTDEV)
HTA	Hydro-Testing Alliance An Alliance to Enhance the Maritime Testing Infrastructure in the EU <a href="https://goo.gl/EZDcA5">https://goo.gl/EZDcA5</a>	2006-2011	EU (FP6-SUSTDEV)
INFRAALERT	Linear infrastructure efficiency improvement by automated learning and optimised predictive maintenance techniques <a href="https://goo.gl/xsnGxo">https://goo.gl/xsnGxo</a>	2015-2018	EU (Horizon 2020)
INTERAIL	Development of a Novel Integrated Inspection System for the Accurate Evaluation of the Structural Integrity of Rail Tracks <a href="https://goo.gl/81fGHP">https://goo.gl/81fGHP</a>	2009-2012	EU (FP7-TPT)
MAINLINE	MAINTenance, renewal and Improvement of rail transport infrastructure to reduce Economic and environmental impacts <a href="https://goo.gl/54x9U1">https://goo.gl/54x9U1</a>	2011-2014	EU (FP7-TPT)
MOBI-ROMA	Mobile Observation Methods for Road Maintenance Assessments <a href="https://goo.gl/fErjY5">https://goo.gl/fErjY5</a>	2011-2013	EU (ERA-NET)
OPTIRAIL	Development of a smart framework based on knowledge to support infrastructure maintenance decisions in railway corridors <a href="https://goo.gl/8RB4cS">https://goo.gl/8RB4cS</a>	2012-2015	EU (FP7-TPT)
PLATINA II	Platform for the implementation of NAIADES <a href="https://goo.gl/ivePvx">https://goo.gl/ivePvx</a>	2013-2016	EU (FP7-TPT)
PMnIDEA	Predictive Maintenance employing Non-intrusive Inspection & Data Analysis <a href="https://goo.gl/geFGzv">https://goo.gl/geFGzv</a>	2009-2012	EU (FP7-TPT)
QUIET-TRACK	Quiet Tracks for Sustainable Railway Infrastructures <a href="https://goo.gl/7SJQVF">https://goo.gl/7SJQVF</a>	2013-2016	EU (FP7-TPT)
ROADAPT	Roads for today, Adapted for tomorrow <a href="https://goo.gl/R6ITJC">https://goo.gl/R6ITJC</a>	2013-2015	EU (CEDR)
RPB HealTec	Road pavements & bridge deck health monitoring/early warning using advanced inspection technologies <a href="https://goo.gl/nQeabn">https://goo.gl/nQeabn</a>	2014-2016	EU (FP7-SME)



Table 4-6 (continued) Projects reviewed in the monitoring and maintenance sub-theme

Project acronym	Project name	Project duration	Source of funding
EU-funded projects			
SABARIS	Stakeholder Benefits and Road Intervention Strategies <a href="https://goo.gl/UpFWeN">https://goo.gl/UpFWeN</a>	2010-2012	EU (ERA-NET)
SAFE-RAIL	Development of an Innovative Ground Penetrating Radar System for Fast and Efficient Monitoring of Rail Track Substructure Conditions (SAFERAIL) <a href="https://goo.gl/uw8QWA">https://goo.gl/uw8QWA</a>	2004-2008	EU (FP6-SUSTDEV)
SENSKIN	'SENSing SKIN' for Monitoring-Based Maintenance of the Transport Infrastructure <a href="https://goo.gl/jdObgF">https://goo.gl/jdObgF</a>	2015-2018	EU (Horizon 2020)
SMART RAIL	Smart Maintenance and Analysis of Transport Infrastructure <a href="https://goo.gl/8xtjFP">https://goo.gl/8xtjFP</a>	2011-2014	EU (FP7-TPT)
SUREBRIDGE	Sustainable Refurbishment of Existing Bridges <a href="https://goo.gl/5JH1ub">https://goo.gl/5JH1ub</a>	2015-2018	EU (FP7-TPT)
TRIMM	Tomorrow's Road Infrastructure Monitoring and Management <a href="https://goo.gl/VYBPq2">https://goo.gl/VYBPq2</a>	2011-2014	EU (FP7-TPT)
USE-IT	Users, Safety, security and Energy In Transport Infrastructure <a href="https://goo.gl/UETJrb">https://goo.gl/UETJrb</a>	2015-2017	EU (Horizon 2020)
Nationally funded projects			
N/A	Information system for decision-making support in the area of road transport safety <a href="https://goo.gl/R0kN9L">https://goo.gl/R0kN9L</a>	2004-2008	Czech Republic
Link and effect model	Link and Effect Model for Maintenance of Railway Infrastructure <a href="https://goo.gl/PdCGOp">https://goo.gl/PdCGOp</a>	2010-2013	Sweden
E-BUS Berlin	Fully electric bus operations including recharging infrastructure <a href="https://goo.gl/S2GXMI">https://goo.gl/S2GXMI</a>	2013-2016	Germany

## 5 Conclusions and recommendations

### 5.1 Research environment and development

European Union (EU) policy relating to transport infrastructure has been continually evolving and strengthening, often as earlier attempts at delivering the intended objectives have fallen short or in response to new developments. The development of the Trans-European Network – Transport (TEN-T) network, which aims to ensure that there is a comprehensive EU-wide transport network that enables passenger and freight transport to easily cross national borders, is a case in point. The policy framework itself, as well as the financial support provided by the European Commission, has been constantly evolving in response to challenges that have been identified with previous approaches. The current policy framework (i.e. the revised TEN-T Guidelines and the Connecting Europe Facility (CEF)), is more comprehensive than the previous framework. It also aims to deliver improved intermodal integration to provide EU support where it is most needed and to contribute better to the EU's climate goals. Similarly, infrastructure charging policy has been constantly evolving. While the principle of fair and efficient pricing has been a long-standing one, its implementation in practice has been much more gradual.

Action on safety has contributed to Europe being one of the safest regions of the world in which to travel, but action on some modes, such as aviation and railways, has been more comprehensive than on others (e.g. roads). Aviation and rail transport have dedicated EU agencies that support the harmonisation of safety standards in the EU. However, policy on road transport has focused on the more important issues from a pan-EU perspective, such as tunnel safety, dealing with critical events and road safety management. EU action to support intelligent transport system (ITS) applications for the various modes has been more recent, but has been proactive in providing the appropriate policy frameworks and in supporting the development and implementation of the applications (e.g. under the CEF).



The way in which the EU's research programmes have addressed transport infrastructure has evolved in parallel to the policy framework, and the associated technological and operational developments. In the successive research programmes, it is possible to identify progress from interoperability and connectivity, through sustainability and efficiency to the current focus on smart mobility.

### 5.2 Research activities and outcomes

Research in relation to the planning of transport infrastructure has evolved and has clearly contributed to practice. From a general perspective, there is now a greater understanding of how to plan better for sustainable transport, taking account of the interaction with the impacts on land use that are intrinsically linked to transport demand. Different concepts and practices are needed at different administrative levels. These have been researched in various projects enabling planners to adopt a more informed approach to transport infrastructure. With respect to the TEN-T network, research has evolved alongside the policy framework, as the focus is now on the planning of an interconnected, multimodal transport network that goes beyond the borders of the EU, rather than on individual research projects. Other research has looked to the longer term to identify future infrastructure needs in light of potential changes to transport technologies, such as new energy sources, increased automation and the changing needs of infrastructure users. A prominent feature of the research over time has been the increasing involvement of a wider set of stakeholders, whose understanding of the issues around the planning of transport infrastructure has, itself, matured. In particular, national research has looked at the local sustainability impacts of infrastructure, such as those on biodiversity, landscape fragmentation, and the pollution of soil and water.

Research into infrastructure assessment techniques has developed in parallel with policy needs as a result of the close link between the two. The need to appraise and evaluate infrastructure better has resulted in many research projects that have tried to improve the assessment methodologies used and the monetary values included in economic analyses. Research has also paid attention to evaluating the external costs of transport and to reaching a better understanding of the wider economic and environmental impacts of transport infrastructure. This has again responded to associated policy needs to ensure that infrastructure is developed for the good of the economy, society and the environment more generally. Research has examined ways of improving the way in which ex-ante evaluations and ex-post evaluations work together to inform the overall assessment process better. A number of forecasting tools have also been developed with the aim of better informing future policy making.

Research on pricing and financing has also been closely linked to policy needs and has influenced the development of some aspects of the policy framework. The external costs of transport are not only important in the appraisal of transport, as noted above, but also in relation to its pricing.

Since at least the 4th Framework Programme for Research and Technological Development (FP4), research has been concerned with various aspects of applying different pricing mechanisms, particularly on social marginal cost pricing in which each user is expected to pay a price equivalent to the full social marginal costs imposed by their use of the infrastructure. Such approaches to pricing are economically the most efficient means of setting prices as users face the external costs of their transport use, including those imposed on the environment. However, as such an approach is difficult to achieve in practice, research has also looked at 'second-best' approaches.

An important element of changing the pricing structure of transport is user acceptance, which research has found is closely related to how the revenues from pricing are used. The acceptability of different pricing approaches and revenue uses have been the subject of research, as has the way in which such pricing might be introduced. In a time of limited public resources, alternative means of financing the development of transport infrastructure has also been the subject of research. The development of infrastructure could, at least partially, be financed through pricing for its use, but other approaches, such as public-private partnerships (PPPs), are also possible. Research has focused on various aspects of the financing of large infrastructure projects in particular, including the choice of financing scheme, the practicalities involved (including the design of contracts) and the challenges of implementing social marginal cost pricing within a PPP.

A large body of research has looked at various different aspects of the construction of transport infrastructure. This includes looking at how to improve the design of infrastructure (which has included more people-centric approaches), and the environmental performance of infrastructure construction and its eventual use (such as reduced noise levels). Projects have also explored how to construct infrastructure to improve its operational functionality (e.g. making it safer and reducing its maintenance costs).

A number of research projects have focused on infrastructure with a higher technical content, such as bridges and tunnels, in terms of improving their construction and facilitating their maintenance. The materials used in the construction of infrastructure have also been the subject of EU-funded research.

Some projects have examined ways of treating conventional materials, such as asphalt and concrete, to improve their performance. Others have focused on how best to use recycled materials in infrastructure construction to reduce resource use.

Many more recent projects have researched what might be considered to be ancillary infrastructure (e.g. that supporting the use of vehicles using alternative powertrains). While some projects have focused on demonstrating the viability



of hydrogen as a transport fuel, others have looked at the implications of increasing the number of electric vehicles (EVs) on the electricity distribution network and on ways of speeding up the charging of these vehicles. Many of these projects have direct practical applications, as they have responded to the wider needs of improving the quality of infrastructure, reducing costs and improving environmental performance.

Many aspects of the management and governance of transport infrastructure have been covered in different research projects. Projects that focus on the efficiency of the operation of transport infrastructure tend to focus on a single mode or on a specific type of intermodal connection, such as around a port. This is to be expected as the operational challenges differ between modes. Other research focuses on interconnectivity within and between modes, and on interoperability between different modes. Such projects tend to focus on identifying missing links or barriers to interconnectivity and interoperability, and then examining ways of overcoming these. Another set of projects looks at improving the performance of infrastructure, the resilience of infrastructure to extreme weather events, and the safety and security of infrastructure. For all of these, the design and operation of infrastructure is important, as are strategies for responding to events when they occur, all of which have been the subject of research to some extent. There is also an increasing interest in the use of ITS technologies for many different aspects of the management of infrastructure, many of which are being researched. New areas of research, which will have implications for the management of infrastructure (e.g. automated driving and big-data applications) are also becoming more prominent.

Research has been, and is being, undertaken into various technologies and procedures to support the monitoring and maintenance of infrastructure. A number of research projects have explored the potential to use sensors and other detection technologies to support the maintenance of rail tracks. However,

fewer projects have investigated the use of such technologies on roads, where bridges have been a particular focus. Other projects have explored the potential to use enhanced computing capabilities and ITS to identify future maintenance needs. Research has also explored new ways of repairing infrastructure and of developing infrastructure management tools, which include the monitoring and maintenance of infrastructure as part of the wider management of the infrastructure.

### 5.3 Indications for future research

While progress has been made in relation to planning infrastructure, more research will be needed to ensure a common understanding and awareness at all levels of government of new sustainable planning concepts and practices. Research will also need to respond to wider social trends, and to the changing perceptions and preferences of those using transport infrastructure and of society more generally. As various transport technologies evolve, and users respond to these, research will be needed to understand better the implications for planning transport infrastructure to ensure that those technological developments can be fully integrated in an efficient and sustainable transport network.

There are a number of research challenges in relation to the assessment (i.e. the appraisal and evaluation) of transport infrastructure. The recent economic crisis has highlighted a need to understand better the wider economic effects of infrastructure to improve its initial appraisal, including that of alternative options. There is also a need to improve ex-post evaluation methodologies to help learn from experience. Such findings can also help to inform adjustments to the appraisal process, not least in helping to inform the derivation of probability distributions used in risk analysis. Research is also needed to identify the appropriate information that will need to be collected during the ex-ante evaluation to facilitate the ex-post evaluation. More research is also needed to understand the implications of different forms of infrastructure finance, from PPPs to projects financed by revenues, on the ex-ante evaluation of projects.

Significant research has been undertaken with respect to the pricing and financing of transport infrastructure. However, there is still a need to synthesise and disseminate this research better so that it has a practical impact on policy making and the implementation of pricing schemes. In spite of the research that has been undertaken, the implementation of charging schemes aimed at taking account of transport's externalities still faces problems associated with public and political acceptability. This suggests that further research to identify ways of increasing acceptability would be beneficial.

The development of better construction techniques and materials is an ongoing process in response to technical developments and wider changes in the economy, environment, society and policy. Research is needed to speed up construction (including off-site construction methods), make infrastructure more durable and better from an operational perspective, reduce the disruption caused by infrastructure maintenance and maximise the use of secondary raw materials in the construction process. A better understanding of the whole-life costs of construction, taking

account of resource availability and greenhouse gas (GHG) balances, would also be beneficial. With respect to ancillary infrastructure, research needs to focus on improving the way in which EVs are charged and on ensuring that the construction and maintenance of infrastructure takes account of developments in cooperative intelligent transport systems (C-ITS), particularly how these might impact on the demands imposed on infrastructure.

As in other areas associated with transport infrastructure, research relating to the management and governance of infrastructure will need to respond to the development of new technologies and the changing needs of society more generally. The rapid developments in information and communication technologies provide many opportunities to improve the way in which infrastructure is managed. Several of these will require research into how best to apply them while delivering wider social objectives. Such technologies will also need to become the focus of research themselves as they require the handling and processing of potentially sensitive and/or personal data, which may raise questions of public and political acceptability.

As with other sub-themes, technology that has the potential to be beneficial to the monitoring and maintenance of infrastructure is developing fast. Research, including that on detection, new materials and maintenance support tools, should continue to support the development, testing and application of new technologies.

### 5.4 Implications for future policy development

The review undertaken in this report suggests that, for planning, policy needs to look at the further integration of the various land use and transport planning instruments, while reflecting the different transport patterns across Member States. In this respect, it will be important to understand the transferability of results better in different contexts. There is also a need for policy to consider the interfaces between the EU's TEN-T network and the networks of neighbouring countries with a view to optimising international transport corridors and traffic flows.

Regarding the assessment of transport infrastructure, there is a need for policy to support the development and application of ex-ante and ex-post evaluations. It will also be important for the policy framework to ensure that any changes to a project in the course of its implementation are appropriately assessed for their implications on costs and for their wider impacts on the economy and the environment.

The policy framework for transport pricing and financing is well developed and often takes account of principles such as the 'user pays' and 'polluter pays', which are enshrined in the overall decision-making framework, not least at the EU level. However, the implementation of pricing in practice often falls short of these high-level principles. Policy development in this area needs to focus on achieving a more streamlined and standardised approach to infrastructure charging that is based on well-researched criteria.



Policy should support research and innovation in construction and the application of such innovation in practice. In this respect, improved design standards or green public procurement could be beneficial. Policy support is required to improve standards and procurement procedures to ensure that the contribution of road surfaces to noise pollution is addressed.

Many aspects of the management and governance of infrastructure pose challenges for policy, as policy's role is largely an enabling one (i.e. to ensure that legislative barriers are removed where appropriate and to provide relevant financial support where necessary). The current TEN-T/CEF framework aims to contribute to this from the perspective of the efficiency of operations, interconnectivity and interoperability in the current programming period. Therefore, its progress in this respect should be monitored.

Policy in the area of resilience to extreme weather events, safety and security could take the form of relevant standards. However, standards will be more appropriate for some modes and infrastructure than others. So, again, in many cases, the role of policy is an enabling one. A policy framework for ITS is emerging, but will need to be kept under review as the technologies and their range of applications develop. At some point, the introduction of appropriate standards to ensure interoperability and security might be necessary. The monitoring and maintenance of infrastructure are aspects of its management, so there are similar implications for policy development.



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## 7 Glossary

*The following abbreviations have been used in this review.*

ATM	Air traffic management
CBA	Cost-benefit analysis
CEDR	Conference of European Directors of Roads
CEPS	Centre for European Policy Studies
EIB	European Investment Bank
ERA	European Railway Agency
ERA-NET	European Research Area Network
ERRAC	European Rail Research Advisory Council
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
EU	European Union
EV	Electric vehicle
FP	Framework Programme for Research and Technological Development
FRP	Fibre-reinforced polymers
IT	Information technology
ITS	Intelligent transport system
LCA	Life-cycle analysis
LCC	Life-cycle cost
MCA	Multi-criteria analysis
NRA	National road administration
PPP	Public-private partnership
RIS	River information services
SMC	Social marginal cost
TEN-T	Trans-European Network – Transport









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Publication: Research Theme Analysis Report Transport Infrastructure  
Luxembourg: Office for Official Publications of the European Union

ISBN: 978-92-79-63148-1  
DOI: 10.2832/13882  
Catalogue: MI-04-16-974-EN-N

