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Research and innovation in transport infrastructure in Europe

An assessment based on the Transport Research and Innovation Monitoring and Information System (TRIMIS)

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Contents

Abstract

For transport infrastructure to be cost-efficient and ready for future needs, adequate research and innovation (R&I) in this field is necessary. This report provides a comprehensive analysis of R&I in transport infrastructure. The assessment follows the methodology developed by the European Commission's Transport Research and Information Monitoring and Information System (TRIMIS). The report critically addresses research by thematic area and technologies, highlighting recent developments and future needs.

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Executive summary

The report presents a comprehensive analysis of research and innovation (R&I) in transport infrastructure in Europe in the last years, focusing on European Union (EU) funded projects. It identifies progress in several thematic fields and technologies. It also highlights the relevant policy context and the market activities both in Europe and outside.

Policy context

In May 2017, the European Commission (EC) adopted the Strategic Transport Research and Innovation Agenda (STRIA) as part of the 'Europe on the Move' package (European Commission, 2017a; 2017b), which highlights key transport R&I areas and priorities for clean, connected and competitive mobility. The STRIA roadmap for transport infrastructure covers R&I on physical transport networks, terminals and intermodal nodes, information systems and refuelling and electrical supply networks, which are necessary for the safe, secure operation of road, rail, civil aviation, inland waterways and shipping.

A major challenge for infrastructure concerns the growing pressure on existing transport systems, combined with regularly underfunded maintenance activities and infrastructure vulnerabilities to man-made or natural disasters. In this context, life-cycle optimisation and integrated efficient operations can lead to improvements in the existing and future infrastructure stock, regarding both safety and serviceability.

Furthermore, the upgrading of transport infrastructure to support new mobility demand appears challenging, considering the different state of infrastructure in Member States (MS), and the different priorities and needs. Considering road transport for example, connected and automated vehicles have the potential to change the transport system. Particular challenges are foreseen for the transition period, and, for example, the coexistence of conventional and automated vehicles. IoT (Internet of Things) devices, traffic management centres and digital maps, together with the information and secure data transfer, are part of the physical and digital infrastructure for connected and automated road transport.

Other transport modes (rail, aviation, waterborne) are equally influenced by the digital transformation of transport, mobility and logistics.

In December 2018, the European Commission has started to update the STRIA roadmap on transport infrastructure in close cooperation with MS and industry stakeholders. The roadmap will include an action plan for R&I initiatives to address the main transport infrastructure challenges.

Considering the above, this report supports the STRIA infrastructure roadmap update, by assessing research carried out in transport infrastructure. The analysis identifies the current state of play and describes several developments that future R&I initiatives should consider. The analysis is based on the European Commission's Transport Research and Innovation Monitoring and Information System (TRIMIS).

Main findings and conclusions

- Between 2007 and 2013, the 7th Framework Programme (FP7) funded 92 projects relevant to transport infrastructure, with a total budget of € 563 million. Most of the projects were funded through the transport and security programmes of FP7. From 2014, projects were funded through the Horizon 2020 programme; 142 relevant projects have been identified in the TRIMIS database, with around € 500 million of total funding. This amount is likely to grow as several funding calls are yet to be launched. 87 % of this budget has been funded through the Smart, Green and Integrated Transport, and, the Secure, Clean and Efficient Energy programmes within the Societal Challenges section of H2020.
- Spending on infrastructure research under the Horizon 2020 (H2020) Framework Programme peaked in the beginning of 2018. Road, rail and multimodal transport receive greatest interest, while waterborne transport receives the smallest amount of funds for infrastructure research amongst all modes.
- From a text analysis on scientific research from the Scopus database, the number of publications in transport infrastructure in general has an increasing trend from year to year: starting from 75 in 2004, and rising to 531 in 2018. "Maintenance" and "technological changes" keywords increased significantly in the last two years. Likewise, research on "construction" seems to have increased in the last year.

- Similar technologies are researched in FP programmes at different development phases. An effort to reduce duplication of research should be made.
- There has been significant funding awarded to projects dealing with crisis management, including developing a standardisation of security of infrastructure and tools to provide advice in the event of a crisis.
- Limited research has been done into the effects of using unconventional transport systems for freight.
- Many projects research how to monitor structures to better plan maintenance, something that can lead to better utilisation of the infrastructure.
- The measurement of carbon emissions during the construction, maintenance and eventual deconstruction or recycling of infrastructure has not received much research attention.
- There have been large projects researching multiple aspects of improved railway operational efficiency.
- Research project outcomes are well documented in Europe; however, these outcomes are not always accessible to stakeholders or they may not be aware of them.

Altogether, this report provides a comprehensive and up-to-date review of transport infrastructure R&I across Europe. The findings and the insights into the current R&I status and future needs, help the STRIA working group (WG) to better identify R&I activities and provides valuable information to transport infrastructure stakeholders.

Related and future JRC work

The TRIMIS team is consolidating and expanding the data repository to better assess R&I efforts of projects not funded by the EU or MS. As part of this effort, information will be added on technologies, patents and publications, and various other topics of interest, including on transport infrastructure. TRIMIS will continue to provide support to STRIA and, on the basis of its research, provide recommendations to policymakers.

Quick guide

The report is structured in the following manner:

Chapter 1 gives a brief introduction and background on transport infrastructure research. Chapter 2 provides the scope of the report together with a methodological background. Chapter 3 provides the market context and Chapter 4 the policy context. Chapter 5 highlights infrastructure related project statistics. Chapter 6 provides a quantitative assessment of the technologies in framework programmes. Chapter 7 provides some insights from international academic research on transport infrastructure. Chapter 8 shows the R&I assessment, dividing infrastructure research in five sub-themes. Finally, Chapter 9 provides the conclusions.

1 Introduction

Transport infrastructure, which includes physical networks, terminals and intermodal nodes, information systems, as well as refuelling and electrical supply networks, is necessary for the safe, secure operation of road, rail, civil aviation, inland waterways and shipping and is crucial to the European Union's (EU) economic growth and social development.

Unlike other transport operations, transport infrastructure is owned by public sector organisations at country or regional level. Where the private sector manages infrastructure, it is subjected to various degrees of economic regulation to comply with policies set by Member States (MS).

An issue of concern arises from the growing pressure on existing transport systems, combined with regularly underfunded maintenance activity, the growing digital connectivity, infrastructure vulnerabilities to man-made or natural disasters and the carbon efficiency of infrastructure reuse. Life-cycle optimisation and integrated efficient operation can lead to improvements in the existing and future infrastructure stock.

Furthermore, innovations or disruptions that influence user's behaviour (e.g. MaaS – Mobility-as-a-Service, and CCAM – Cooperative connected and automated mobility) impact the optimal use of existing infrastructure and require a discussion on future standards and requirements.

In order to address current socio-economic challenges within an ever-changing complex and competitive environment, the transport sector requires new technological developments. This will be achieved through research and innovation (R&I), which allows new quality standards in relation to the mobility of people and goods.

In May 2017, the European Commission (EC) adopted the Strategic Transport Research and Innovation Agenda (STRIA) as part of the 'Europe on the Move' package (European Commission, 2017a; 2017b), which highlights main transport R&I areas and priorities for clean, connected and competitive mobility.

The STRIA roadmaps set out common priorities to support and speed up the research, innovation and deployment process leading to technology changes in transport.

Seven STRIA roadmaps have been developed covering various thematic areas, namely:

- Cooperative, connected and automated transport;
- Transport electrification;
- Vehicle design and manufacturing;
- Low-emission alternative energy for transport;
- Network and traffic management systems;
- Smart mobility and services; and
- Infrastructure.

As of July 2019, the roadmap on Cooperative, connected and automated transport has been updated, while three others (on Smart mobility and services, Infrastructure and Low emission energy for transport) are in the process of being updated with the involvement of MS and industry stakeholders.

An effective monitoring and information mechanism must support the implementation of STRIA. The ECs Joint Research Centre (JRC) has developed the Transport Research and Information Monitoring and Information System (TRIMIS) to provide a holistic assessment of technology trends and transport R&I capacities, publish information and data on transport R&I, develop analytical tools on the European transport system and to support the implementation of STRIA (Tsakalidis et al. 2018). TRIMIS was funded under the Horizon 2020 Work Programme 2016-2017 on Smart, Green and Integrated transport (European Commission, 2017c).

This report focuses on the STRIA roadmap for transport infrastructure. The current roadmap identifies several research needs for the years to come. It identifies a number of areas where consumer or user acceptance will be needed, especially in the area of charging and connected road mobility.

The updated STRIA infrastructure roadmap (INF) will include an action plan for R&I initiatives, over different thematic areas. At the time this report is being prepared, eight thematic areas have been identified:

- Governance.
- Life-cycle and asset management.

- Financing, Pricing and Charging.
- Technology and digitalization.
- Multimodality, interoperability and interconnectivity.
- Safety and security.
- Sustainability, environment and resilience.
- Logistics.

For each thematic area, a package of actions will be proposed, classifying them in "Policy actions", "Management actions" and "Technological actions".

The present report supports this process by assessing R&I in INF, based on TRIMIS. It provides a comprehensive analysis of selected infrastructure research projects that are financed by the 7^{th} Framework Programme (FP7) and the Horizon 2020 (H2020) Framework Programme (FP). These findings can help transport infrastructure stakeholders, including policy makers, regulators, transport service providers, and standardisation bodies. Furthermore, insights into the current status and future needs helps the STRIA working group (WG) to better identify R&I activities

2 Methodological background

The main goal of this report is to thoroughly review transport infrastructure related EU funded projects. To do so, three actions were necessary, namely:

1. The consolidation and further development of the TRIMIS project and programme database.
2. The development of a methodology for the identification and assessment of the technologies researched within FPs.
3. The conceptual framing for the project assessment.

A brief description of these steps is provided in the following paragraphs.

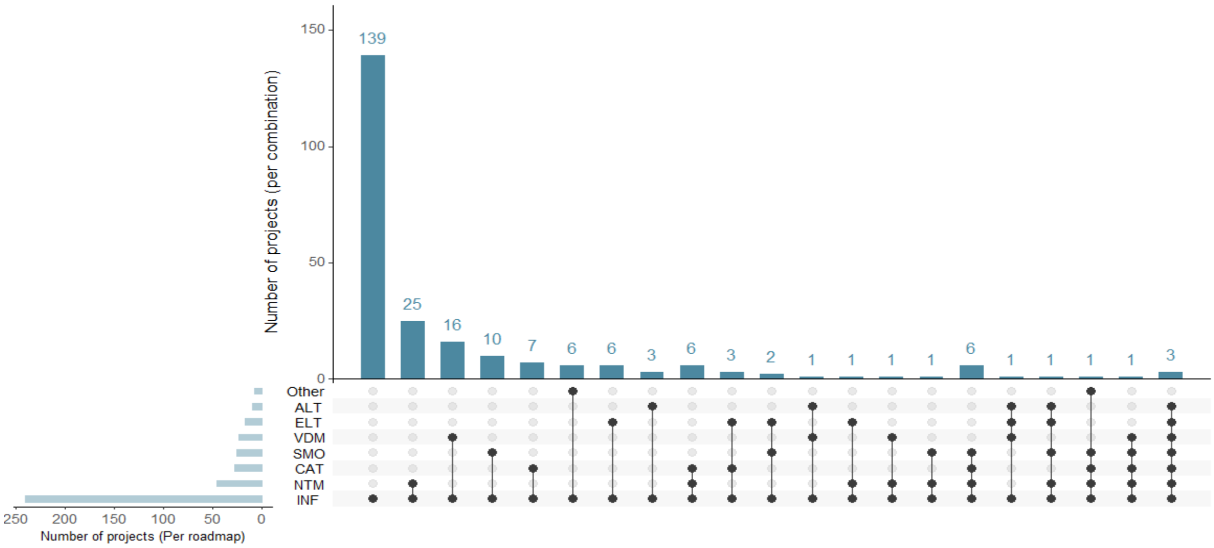
2.1 Database development and labelling

TRIMIS hosts a continuously updated database of EU and MS programmes and projects (currently over 7 000) on transport R&I. Projects funded by the European FPs are retrieved through an automated data interchange with the Community Research and Development Information Service (CORDIS), while projects funded by MS are inserted manually by national contact points. Projects are then evaluated and labelled on several dimensions, after which they are published in TRIMIS (van Balen et al., 2019a).

A central step is to identify those projects that fall under the INF roadmap. The scope of the INF roadmap was defined by the original STRIA roadmap, and transport specialists with a deep understanding of all STRIA roadmaps manually assigned the projects. Considering that many projects cover infrastructure dimensions to some extent, only those projects that cover a considerable infrastructure research component in the project description were assigned to the INF roadmap. In such a case, a project can also be assigned to multiple roadmaps. An overview on the extent to which INF projects overlap with other roadmaps is depicted Figure 1, based on 240 FP7 and H2020 projects, shows how often the keywords of each theme were detected (left horizontal bars) in the projects' objectives, and how often a certain combination of keywords occurred (vertical bars).

The specialists also assessed the projects on several other variables, including the mode of transport and geographical focus of the project. Through discussions and interrater reliability assessments, the quality of the labelling is assured.

Figure 1. Overlap between Infrastructure projects with other STRIA roadmaps



(*) Alternative Energy (ALT); Electrification (ELT); Vehicle Design & Manufacturing (VDM); Connected & Automated Transport (CAT); Smart Mobility (SMO), Network & Traffic Management (NTM), Infrastructure (INF). *Source*: van Balen et al., 2019b.

As the figure suggests, some projects are cross-cutting and include elements of other STRIA roadmaps as well. This should be taken into consideration when interpreting the results that are provided in this report.

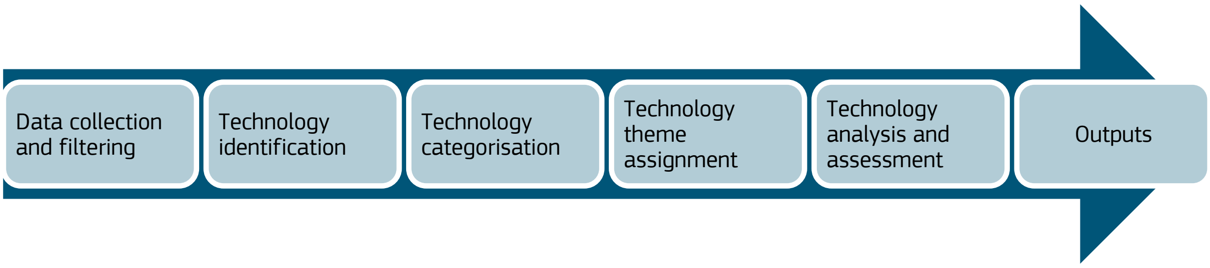
2.2 Identification and assessment of the technologies researched within FPs

One of the sub-tasks of TRIMIS is the creation of an inventory and regular reporting on new and emerging technologies and trends (NETT) in the transport sector (Gkoumas et al. 2018). In doing so, a taxonomy, assessment and monitoring framework is proposed (Gkoumas and Tsakalidis, 2019) which supports innovation management at various levels, thus providing insights to the sector's stakeholders (i.e. researchers, business operators, national authorities and policymakers) while backing the current transport systems' transformation through technological advances.

The TRIMIS NETTs analysis currently focusses on technologies researched in European FP, specifically FP7 and H2020 projects from the TRIMIS database.

Figure 2 provides an overview of the methodological steps undertaken.

Figure 2. Technology assessment methodological steps



2 242 projects fall within the scope. Within these projects, 797 technologies were identified within 45 technology themes through a Grounded Theory approach (Glaser and Strauss, 1967). An iterative approach led to the development of a consistent taxonomy for transport technologies and technology themes.

First, the results of a study that identified technologies within European transport research projects (INTEND, 2017) were analysed by three researchers who have complementary experience in the field of transport innovation and who have individually assessed the technology list. Based on this review, the researchers came up with a standardised approach on what constituted a distinct technology and how to label them.

Following these discussions, all 2 242 projects descriptions were read and flagged when a technology was mentioned. This filtering exercise was required because EU-funded projects also cover non-technology focused projects like, for instance, those that encourage collaboration between different infrastructure managers. Once a technology was flagged in the project description, another researcher would validate the flagging and write down the technology name.

In a next step, the full list of technologies was evaluated, and the labelling of similar technologies was aligned. The labels were inspired by existing taxonomies, such as those under the Cooperative Patent Classification (CPC, 2019).

When the technology list was established, a number of overarching technology themes were defined. Themes enable a better understanding of how technologies cluster together and which fields of research receive relatively greater interest. An extensive list of themes was created and consequently reduced to the minimum number of themes under which all technologies could still be logically placed. This process led to a total of 45 themes.

In a final step, all projects were assessed on whether they focused on transport infrastructure. If so, the associated technologies and their themes were highlighted. The funds associated with each technology were determined by linking them with the total project budget. If multiple technologies were researched in the project, the budget allocated to the technology of interest was determined by dividing the project budget by the number of associated technologies. The limitations of this attribution approach are acknowledged, but is considered to be transparent and appropriate in the absence of technology-budget reports.

In a consequent step, a set of metrics was established to assess the 80 technologies identified within the INF roadmap. These metrics are intended to indicate the potential for the technology to be taken forward to application through the level of support for its development.

2.3 Project assessment

Using the data in TRIMIS, recent programmes that have funded research in transport infrastructure topics have been identified. All related projects within the last two framework programmes (FP7 and H2020) have been included. In this report, each section considering the research performed under one of the sub-themes includes a table of projects considered during the review of that sub-theme.

Table 1 (left column) reports the sub-themes identified. These are linked to the draft STRIA 2019 transport infrastructure roadmap sub-themes identified at the time this report was under development.

Table 1. Transport infrastructure sub-themes

Sub-themes	STRIA 2019 Roadmap sub-themes*
Governance, planning and regulation	– Governance
Pricing, taxation and financing	– Financing, Pricing and Charging
Intermodality, interoperability and integration of transport system	– Multimodality, interoperability and interconnectivity – Logistics
Life-cycle optimisation of assets	– Life cycle and asset management
Operation, efficiency and resilience	– Safety and security – Technology and digitalization – Sustainability, environment and resilience

* The STRIA roadmap 2019 updating was still ongoing in September 2019

By adopting this clustering it is possible to assess R&I findings focusing on specific areas of interest, give ideas on which areas have been left out until now, and compare developments.

A complete table of all projects considered in this report, including the sub-themes that they are relevant to, is included in Annex 1.

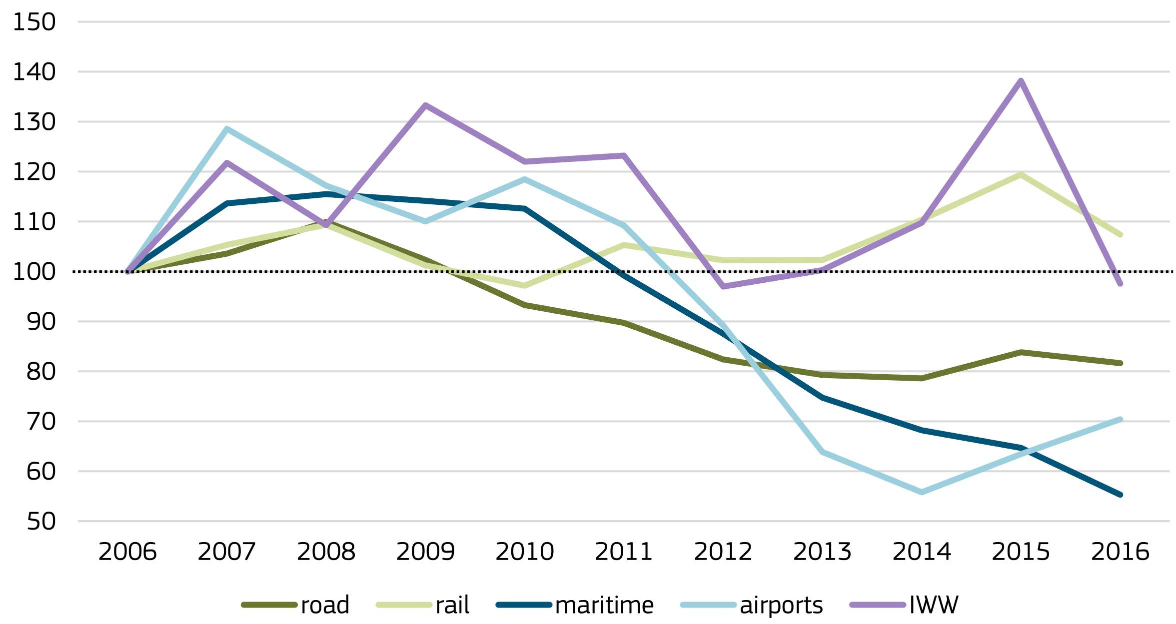
3 State of transport infrastructure

There is robust evidence on the direct relation between quantity and quality of transport infrastructure and the level of economic development (Rodrigue, 2017). Notwithstanding the negative externalities of transport, it is argued that investments in efficient transport systems benefit users in terms of time savings and contribute to wider economic and social benefits such as increased productivity, employment and investment effects.

Since the global economic crisis in 2008, the EU has invested less in transport infrastructure. According to a recent study of the EC on current trends and issues in the transport sector[1], this lack of investment has held back modernisation of the EU's transport system. The European Investment Bank (EIB) estimates that the infrastructure investment gap in the mobility sector is € 50 billion annually in the EU, which represents 0.38 % of the gross domestic product (GDP)[2].

Figure 3 shows that investment levels in road, maritime ports and airports have significantly dropped from 2006 levels. Registered investment in maritime ports in 2016 in the EU is approximately half the one for 2006/2007. For roads and airports, the ratio between 2016 and 2006 investment levels is around 0.8 and 0.7, respectively. However, investment efforts in rail and inland waterways (IWW) infrastructure have been upheld or even increased slightly from 2006 levels. These investment levels are justified on the grounds that rail and inland waterways are seen as more sustainable transport modes.

Figure 3. Investment levels in EU transport infrastructure by mode with respect to 2006 levels (=100)



Source: OECD stats

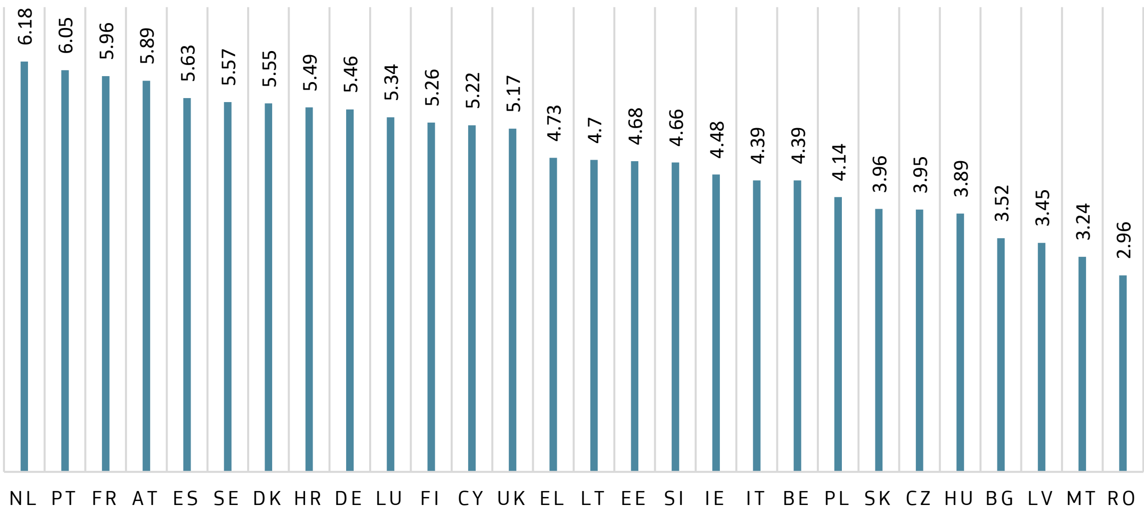
Despite the efforts of the EU cohesion policy, the quality of transport infrastructure still presents significant differences between Member States. The availability and quality of transport infrastructure is particularly low in the Eastern part of the EU.

Figure 4 illustrates the case of road infrastructure. The Netherlands scores 6.18 in the quality index of roads[3], whereas Romania scores 2.96. The index is based on an executive opinion survey of business leaders on the extensiveness and condition of road infrastructure, and takes values between 1= extremely poor (among the

1 European Commission, DGMOVE (2018), Transport in the European Union, Current trends and Issues, April 2018
2 European Investment Bank (2018), Investment report 2018/2019, Retooling Europe's economy
3 World Economic Forum (2018), The Competitiveness Report 2018, available at: http://www3.weforum.org/docs/GCR2018/05FullReport/TheGlobalCompetitivenessReport2018.pdf

worst in the world) and 7 = extremely good (among the best in the world). The Survey provides a yearly evaluation of critical aspects of competitiveness for which statistical data is missing.

Figure 4. Quality index of road infrastructure in the EU



Source: World Economic Forum Global Competitiveness Report 2018

Beyond the need for investment in basic transport infrastructure to achieve growth and cohesion goals, the EU faces a challenge to adapt the design and management of transport infrastructure in view of new technology developments (e.g. connected and automated vehicles), environmental requirements (e.g. low-carbon fuels) and emerging business models (e.g. MaaS - mobility-as-a-service).

The deployment of alternative fuels infrastructure has made considerable progress in recent years. According to the European Alternative Fuels Observatory[4], in 2019, there are around 143 000 publicly accessible electricity charging points in the EU, out of which 24 000 are fast charging points, which represents an average ratio of 10 electric vehicles (EVs) per charging point. This deployment is, however, far from uniform in the EU. The four top-selling EV markets (Germany, France, Netherlands and the UK) concentrate 76 % of public charging infrastructure and also 75 % of the EVs. A recent study by T&E[5] estimates the initial need for public investment will gradually reduce and in the period 2020-2025, the cumulative cost of public charging is estimated at € 12 billion, a small fraction of the € 100 billion invested by the EU every year in transport infrastructure.

The deployment of the infrastructure needed for Cooperative Intelligent Transport Systems (C-ITS) is still at the early stages but a recent study[6] shows that the deployment of C-ITS is clearly beneficial at an EU level, with Benefit-Cost Ratios (BCRs) ranging from 2 to 8 achieved in 2030 for the full range of deployment scenarios.

[4] https://www.eafo.eu/alternative-fuels/electricity/charging-infra-stats

[5] https://www.euractiv.com/wp-content/uploads/sites/2/2018/09/Charging-Infrastructure-Report_September-2018_FINAL.pdf

[6] https://ec.europa.eu/transport/sites/transport/files/2016-c-its-deployment-study-final-report.pdf

4 Policy context

4.1 Transport infrastructure in European transport policy

The development of EU-wide transport infrastructure has traditionally been a key part of the single market policy. The development of a trans-European transport network (TEN-T) dates back to the Maastricht Treaty in 1992. The first set of TEN-T Guidelines was published in 1996[7] and included a set of maps setting out the infrastructure in each of the then 15 Member States that would comprise the TEN-T, including 14 priority projects known as the 'Essen projects'.

In its 2011 Transport White Paper[8], the Commission signalled a change of approach towards the TEN-T, which was defined in revised TEN-T Guidelines[9]. Regulation 1315/2013 adopts a 'dual layer approach' consisting of the comprehensive network and the core network. The 'comprehensive network' is a Europe-wide multimodal transport network ensuring the accessibility and connectivity of all regions in the Union, including the remote, insular and outermost regions. The 'core network' is the strategically most important part of the comprehensive network on which major European and international transport flows are concentrated. Time-wise, the core network is to be completed by the end of 2030 with the comprehensive network by 2050. Both layers incorporate infrastructure for all transport modes (freight, passenger rail and road routes, inland waterways, motorways of the sea, sea ports, IWW ports and airports) as well as other accompanying measures, i.e. refuelling and charging infrastructure, Intelligent Transport Systems (ITS) applications, equipment and services, etc. Nine 'core network corridors' cover the most important long-distance flows in the core network and are intended, in particular, to improve cross-border links within the Union. Regulation 1315/2013 also introduces the concept of urban nodes in the TEN-T policy. They are intended as starting points or the final destinations (''last mile'') for passengers and freight moving on the TEN-T network and are key points of transfer within or between different transport modes.

Since 2014, financial support for trans-European networks (TENs) in the fields of transport, energy and digital services has been provided by the Connecting Europe Facility (CEF), which, for transport, focuses on removing bottlenecks and bridging missing links, ensuring sustainable and efficient transport systems and optimising the integration and interconnection of different transport modes[10].

Infrastructure policy has also an essential role in the achievement of transport decarbonisation targets set in the 2011 Transport White Paper: 60 % carbon dioxide (CO_2) emissions reduction in 2050 compared to 1990 levels. In these regards, a study commissioned by the TRAN Committee of the European Parliament on transport decarbonisation[11] identified that smart infrastructure pricing, the deployment of alternative fuels infrastructure and multimodal transport aided by ITS as key areas.

Efficient pricing and the internalisation of the external costs in transport have been key topics of the European transport policy. In 1995, the Commission's Green Paper 'Towards Fair and Efficient Pricing in Transport'[12] advocated for a pricing policy that reflected the full social costs of transport use across all modes. The 2011 Transport White Paper insists on a wider application of the 'polluter-pays' and 'user-pays' principles. This is, transport users should pay through charges, taxes, fares or other market-based instruments (e.g. an Emissions Trading System (ETS)) for the infrastructure costs (e.g. maintenance, capital costs) and the external costs (e.g. air pollution, noise and climate change) they generate.

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[7] Decision No. 1692/96/EC of the European Parliament and of the Council of 23 July 1996 on Community guidelines for the development of the trans-European transport network; https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A31996D1692

[8] COM (2011) 144 final, White Paper: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system; https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:en:PDF

[9] Regulation (EU) No 1315/2013 of the European Parliament and of the Council of 11 December 2013 on Union guidelines for the development of the trans-European transport network and repealing Decision No 661/2010/EU Text with EEA relevance; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32013R1315

[10] Regulation (EU) No 1316/2013 of the European Parliament and of the Council 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 Text with EEA relevance; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32013R1316

[11] http://www.europarl.europa.eu/RegData/etudes/STUD/2017/601989/IPOL_STU(2017)601989_EN.pdf

[12] COM(95) 691; Towards fair and efficient pricing in transport, policy options for internalising the external costs of transport in the European Union; http://europa.eu/documents/comm/green_papers/pdf/com95_691_en.pdf

A recent study on transport infrastructure charging and internalisation of transport externalities[13] provides a thorough assessment of the extent to which transport related charges and taxes internalise infrastructure and external costs in the EU. The study concludes that there is considerable room for improvement with respect to infrastructure charging and highlights the importance of internalising externalities along with other non-pricing measures to promote welfare-increasing innovation across all transport stakeholders (including manufacturers, operators, infrastructure managers, etc.).

The 'polluter-pays' and 'user-pays' principles have been reflected in the successive Eurovignette Directives for the case of road infrastructure. The latest review[14] sets common rules on distance-related tolls and time-based infrastructure charges for heavy goods vehicles (HGVs) and allows the application of external cost charges related to noise and air pollution. A number of different pricing models for motorways coexist in Europe. Examples of distance-based road charges for HGVs can be found in Austria, Germany or the Czech Republic. In turn, many HGV tolls are complemented by time-based user charges (vignettes) for passenger cars. In other countries, including France, Italy, and Spain, private tolls are implemented on many sections of the motorway network. To ensure interoperability, Directive 2004/52/EC[15] lays down the common conditions for electronic road toll systems and foresees a European Electronic Toll Service (EETS).

The successive Railway Packages have gradually liberalised rail services and imposed the separation of the infrastructure management from the railway operation, at least in accounting terms. This division requires the introduction of rail access charges for the use of the infrastructure. Recast Directive 2012/34/EU[16] determines that track access charges must be based on "costs directly incurred as a result of operating the train service" and that external cost charges should only increase the overall level of charges if external costs are internalised for road transport.

The EU has also actively promoted the deployment of alternative fuels and electric vehicles. The Directive on Alternative Fuels Infrastructure[17] intends to address the so-called "chicken and egg" problem between vehicles and infrastructure – without a minimum network of recharging/refuelling points, uptake of alternatively fuelled vehicles will be hampered, and vice versa. A central component of the Directive is the requirement for National Policy Frameworks (NPFs) including national targets for deployment of alternative fuels infrastructure, supporting measures and identification of infrastructure needs. The Directive also aims at ensuring interoperability of recharging/refuelling points throughout Europe and cross-border continuity for all modes of transport.

Intermodality is a major goal of EU policy on transport infrastructure. As reflected in the 2011 Transport White Paper, for example, the TEN-T network should prioritise intermodal connecting points and support the development of multimodal freight corridors. In this sense, ITS applications in transport infrastructure driven by recent policy goals (e.g. improved accessibility, low carbon fuels), emerging technologies (e.g. 5G connectivity) and new business models (e.g. MaaS) have a high potential to increase intermodality, synchromodality (that is, the simultaneous usage of multiple transport modes) and, ultimately, to achieve more efficient and integrated transport systems. Examples of recent EU policies supporting the deployment of ITS applications are the development of Single European Sky ATM Research (SESAR) for air transport, the European Rail Traffic Management System (ERTMS) for rail transport and the adoption of ITS Directive[18] for road transport.

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[13] https://ec.europa.eu/transport/themes/sustainable-transport/internalisation-transport-external-costs_en

[14] Directive 2011/76/EU of the European Parliament and of the Council of 27 September 2011 amending Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures Text with EEA relevance; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32011L0076

[15] Directive 2004/52/EC of the European Parliament and of the Council of 29 April 2004 on the interoperability of electronic road toll systems in the Community; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32004L0052

[16] Directive 2012/34/EU of the European Parliament and of the Council of 21 November 2012 establishing a single European railway area; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32012L0034

[17] Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure; https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32014L0094

[18] Directive 2010/40/EU of the European Parliament and of the Council 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; https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32010L0040

4.2 Transport infrastructure in European research programmes

Projects related to the transport infrastructure roadmap have been included in EU funding programmes for many years now. Using the TRIMIS database, recent programmes that have funded research in transport infrastructure topics have been identified. All related projects within the last two framework programmes (FP7 and H2020) have been included. In addition, we have selected other EU-funded programmes with projects finishing from 2017 onwards. In these cases, it should be noted that the figures presented below account for the total number of completed projects within each programme selected and not only for projects finishing from 2017 onwards. Table 2 and Table 3 show these programmes, with the number of relevant projects and the total costs of the projects, which includes both EC funding and own contributions from the project participants.

Table 2. Numbers and values of INF projects funded under FP7

Funding action	Number of projects	Total costs (thousand €)
FP7-ENVIRONMENT	2	14 794
FP7-ICT	8	47 049
FP7-INFRASTRUCTURES	1	10 715
FP7-JTI (Joint Technology Initiatives)	1	30
FP7-NMP (Nanosciences, Nanotechnologies, Materials and new Production Technologies)	4	24 415
FP7-PEOPLE	4	4 679
FP7-SECURITY	16	153 739
FP7-SME	3	3 640
FP7-TRANSPORT	53	303 728

Table 3. Numbers and values of INF projects funded under H2020

Funding action	Number of projects	Total costs (thousand €)
H2020-EU.1.3. - EXCELLENT SCIENCE - Marie Skłodowska-Curie Actions	4	1 689
H2020-EU.2.1. – INDUSTRIAL LEADERSHIP – Leadership in enabling and industrial technologies, including, H2020-EU.2.3. – INDUSTRIAL LEADERSHIP – Innovation in SMEs	2	3 656
H2020-EU.3.3. – SOCIETAL CHALLENGES – Secure, clean and efficient energy, including H2020-EU.3.4.	3	109 677
H2020-EU.3.4. – SOCIETAL CHALLENGES - Smart, Green and Integrated Transport, including, including, H2020-EU.2.1., including, H2020-EU.2.3. – INDUSTRIAL LEADERSHIP – Innovation in SMEs	118	328 784
H2020-EU.3.6 SOCIETAL CHALLENGES - Europe In A Changing World - Inclusive, Innovative And Reflective Societies	1	3 551
H2020-EU.3.7. – SECURE SOCIETIES – protecting freedom and security of Europe and its citizens, including H2020-EU.2.3.	13	52,009
H2020-EU.4.b – Twinning of research institutions	1	996

Between 2007 and 2013, the FP7 programme funded 92 projects relevant to transport infrastructure, with a total budget of € 563 million. Most of the projects were funded through the transport and security programmes of FP7. From 2014, projects were funded through the Horizon 2020 programme; 142 relevant projects have been identified in the TRIMIS database, with around € 500 million of total funding. 87 % of this budget has been funded through the Smart, Green and Integrated Transport, and, the Secure, Clean and Efficient Energy programmes within the Societal Challenges section of H2020.

In addition to the two framework programmes, there are also projects that have been funded through other EU programmes. These other European funding programmes have been selected as they have projects which have finished from 2017 onwards.

4.3 Other European funding programmes

In addition to the FP7 and H2020 funding programmes there are several other research programmes that have supported research projects relating to transport infrastructure. A short summary of the programmes and selected projects from within the programme is provided below.

4.3.1 CEF – Connecting Europe Facility

CEF is a key EU funding instrument to promote growth, jobs and competitiveness through targeted infrastructure investment at European level. CEF is divided into Energy, Telecom, and Transport sectors, with the transport sector receiving € 24.05 billion for the period 2014-2020[19].

CEF Transport focuses on cross-border projects and projects aimed at removing bottlenecks or bridging missing links in various sections of the TEN-T Core and Comprehensive Networks, as well as for horizontal priorities such as traffic management systems. CEF Transport also supports innovation in the transport system to improve the use of infrastructure, reduce the environmental impact of transport, enhance energy efficiency and increase safety.

Although CEF funds many (often very large) transport infrastructure projects, the majority are not considered to represent 'research' or 'innovation'; as a result, TRIMIS includes only a small portion of all the transport infrastructure projects funded under CEF.

HYBRID-INFRA-RAIL's (2016-2020) main objective is to conduct a deployment study with two hybrid units' systems and to improve the rail infrastructure to be able to use the hybrid systems at a large scale. The project covered real-life trials in operational conditions, preparation of design for the necessary battery charging distribution network to enable and support the market uptake as well as a business plan containing the market uptake strategy.

The aim of the project AUTOC-ITS (2016-2018) was to contribute to the deployment of C-ITS in Europe by enhancing interoperability for autonomous vehicles as well as to boost the role of C-ITS as a catalyst for the implementation of autonomous driving. The objectives of the project included pilot testing and evaluation of C-ITS services for autonomous vehicles under the applicable traffic regulation and study its extension to other European countries to help develop European standards for C-ITS platforms.

4.3.2 COST (Co-operations in Science and Technology) Actions

The Co-Operations in Science and Technology (COST) programme has also funded research in transport infrastructure, focussing on enhancing the effectiveness of funding from Member States through cross-border cooperation.

During the FP7, COST Actions allowed the interconnection of € 5 billion in national research and technology projects with a COST investment of € 250 million. Whilst the majority of the COST Actions are not directly associated with improving transport infrastructure, there were actions specifically related to research on quantifying the value of structural health monitoring (SHM), and on standardising quality specifications for roadway bridges at a European level.

The majority of the COST Actions were completed prior to 2007, with ATARD (2015-2019) being the only recent Action completed that is included in TRIMIS. This project was aimed at investigating the relationship between air transport and regional development by enhancing collaborative research and networking. A

[19] CEF Transport (2014-2020) https://ec.europa.eu/inea/en/connecting-europe-facility/cef-transport

strategic objective was to provide evidence-based information to society and political stakeholders on emerging scientific and social challenges.

There are some relevant COST Actions that are very recent, and do not appear in the TRIMIS database yet. The COST Action TU1402[20] (2014-2019) was aimed at quantifying the value of structural health monitoring (SHM). This Action provided scientific evidence of a high value of SHM and its boundary conditions, an industrial and societal impact for the infrastructure design and management, and accessibility to the scientific field for quantifying the value of SHM. The conclusions from this Action were that SHM constitutes significant reductions in both risk and expected operational expenditure.

The COST Action TU1406[21] (2014-2019 (results not yet published)) was focused on standardising quality specifications for roadway bridges at a European level. The main objective of the Action was to develop guidelines for the establishment of quality control plans for roadway bridges, by integrating the most recent knowledge on performance assessment procedures with the adoption of specific goals. The guidelines focus on bridge maintenance and life-cycle performance at two levels: (i) performance indicators, (ii) performance goals. By developing new approaches to quantify and assess the bridge performance, as well as quality specifications to assure an expected performance level, bridge management strategies will be significantly improved, enhancing asset management of ageing structures in Europe.

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

The LIFE programme is the EU's funding instrument for the environment and climate action created in 1992. The current funding period from 2014 to 2020 has a budget of € 3.4 billion[22]. The programme is divided into two sub-programmes: Environment, which covers nature conservation projects, and Climate, which covers areas such as renewable energy, energy efficiency and farming/land use. Given the wide range of projects researched in the LIFE programme, there has been a number of projects overlapping into the transport infrastructure roadmap.

The LIFE IMPACTO CERO (2013-2017) project had the objective of designing and testing an anti-bird-strike screen for high-speed railway lines, which would protect common and endangered bird species particularly in protected areas. The overall objective of the CLEAN-ROADS (2012-2016) project was to reduce the environmental problems related to the widespread use of de-icing/anti-ice chemicals (mainly salt) for winter road maintenance. The results from this project provided a tool to help road operators in performing timely and effective road treatments and avoid unnecessary ones. By optimising the number of anti-icing treatments, the concentration of salt in the air and water is reduced.

LIFE HUELLAS (2013-2017) focused on supporting railway infrastructure construction companies to be more sustainable by minimising the environmental impact of their infrastructure works. This was implemented through the development of a tool based on life-cycle assessment methodologies and intelligent systems for use in the planning phase. The tools were demonstrated on a real railway construction project, and the results found that the carbon footprint had been reduced by 13 % and water footprint by 14 % in selected railway sections.

4.4 Transport infrastructure in non-European countries

This section provides brief information on transport infrastructure policy and research in non-European countries.

4.4.1 Transport infrastructure in non-European countries' policies

Based on data collected by the International Transport Forum (ITF)[23], the investment (or gross fixed capital formation) in land transport infrastructure in the OECD (Organisation for Economic Co-operation and Development) as a percentage of the GDP has been slowly declining from 2011 and reached an average value of 0.7 % in 2016. The investment ratio in Western European Countries is 0.7 %, whereas in Eastern and Central European countries it is 1.0 %, thus above the OECD average.

[20] COST Action TU1402 (2014-2019) https://www.cost-tu1402.eu/

[21] COST Action TU1406 (2014-2019) https://www.tu1406.eu/

[22] LIFE programme (2014-2020) https://ec.europa.eu/easme/en/life

[23] International Transport Forum (ITF)/OECD (2018), Statistics Brief: Infrastructure investment, August 2018

In North America, the level of investment in land transport infrastructure has remained stable in the last years at 0.6 %, which also is below the OECD average. In the United States, the American Society of Civil Engineers (ASCE) in its Infrastructure Card Report in 2017[24] acknowledged that highways have been underfunded for a long time, with a $ 836 billion total backlog. Underinvestment is partially due to limitations in the Highway Trust Fund at federal level, which is primarily fed from federal motor fuels tax. With tax levels unchanged since 1993, increased fuel efficiency and the uptake of hybrid and electric vehicles, tax revenues have become an insufficient funding source. A number of States are exploring and testing alternative funding sources, such as mileage-based user fees[25].

China has been heavily investing in transportation infrastructure since the 1990s. Between 2007 and 2015, China has invested annually around 2.2 % of its GDP in road infrastructure and 1.2 % in rail infrastructure[26]. Such investments in the infrastructure network were made possible by large-scale financing, predominantly from the central government and local governments, and increasingly in the form of Public Private Partnerships (PPPs)[27]. As a result of this development, China now has around 27 000 km of high-speed lines in operation in 2018, which represents 64 % of the global total[28]. The development of maritime ports also exemplifies the massive expansion of transport infrastructure capacity. Among the top 10 world container ports, seven are located in China.

This level of infrastructure investment is driven by economic growth but also by ambitious sustainability targets. In 2016, China published its official '13th Five-Year Plan', which aims to create a strong foundation for China's green, robust and resilient economy over the next two decades.

4.4.2 Transport infrastructure strategic research in non-European countries

Transport infrastructure research has been traditionally linked to the government or public bodies and it is a strategic research area in many countries around the world. The TRID (Transport Research International Documentation) database[29] or the World Bank transport research portal[30] present a comprehensive overview of worldwide research in this area.

In the United States (US), the Strategic Plan for Research, Development and Technology of the US Department of Transportation (DOT)[31] defines 'Improving infrastructure' as one of its four critical transportation areas. This area covers issues related to the condition, costs, funding, and delivery of the transport infrastructure, as well as the methods and technologies to increase its durability and resilience. The plan also foresees that emerging technologies (automated vehicles, drones, new traveller services, V2V (Vehicle-to-vehicle) and V2I (Vehicle-to-infrastructure) applications and on-demand mobility options) will place new demands on current infrastructure in terms of infrastructure maintenance and the information and communication technology systems necessary to support them, such as the Global Positioning System (GPS) or Dedicated short-range communication (DSRC).

The vast majority of US DOT's research activities are undertaken by the Department's Operating Administrations (e.g. Federal Highway Administration (FHA) for roads and Federal Aviation Administration (FAA) for air transport). Each agency has its own mission, statutory requirements, and funding sources. Total Departmental Research Development and Test (RD&T) funding at federal level (including all research areas and all Operating Administrations) are around $ 1 billion per annum and have remained stable over the last 10 to 15 years, according to the Strategic Plan for RD&T (FY 2017-2021) of the US DOT[32]. Funding is dedicated to four critical transportation topics, namely, (i) Promoting Safety, (ii) Improving Mobility, (iii) Improving Infrastructure, and, (iv) Preserving the Environment.

The Transportation Research Board (TRB), a program unit of the National Academy of Sciences, Engineering and Medicine, is a worldwide reference in transport-related research and manages the National Cooperative

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24 https://www.infrastructurereportcard.org/cat-item/roads/

25 http://www.mbufa.org/where.html

26 Oxford economics (2017), Global Infrastructure Outlook

27 Qin, Y. (2016), China's Transport Infrastructure Investment: Past, Present, and Future, Asian Economic Policy Review, 11, 199–217

28 https://www.railjournal.com/passenger/high-speed/ten-years-27000km-china-celebrates-a-decade-of-high-speed/

29 https://trid.trb.org/

30 https://www.worldbank.org/en/topic/transport/research

31 https://www.transportation.gov/sites/dot.gov/files/docs/USDOT-RD%26T-Strategic-Plan-Final-011117.pdf

32 https://www.transportation.gov/administrations/assistant-secretary-research-and-technology/dot-five-year-rdt-strategic-plan

Research Programmes (CRP) organised by transport mode. These major research programmes are sponsored by different organisations. For example, the National Cooperative Highway Research Program is sponsored by the member departments of the American Association of State Highway and Transportation Officials (AASHTO) in cooperation with the FHA while the National Cooperative Rail Research Program is sponsored by the Federal Railroad Administration (FRA). Individual projects are conducted by contractors with oversight provided by volunteer panels of expert stakeholders.

China’s high ambitions for a sustainable and innovative transport system are supported by a strong transportation research output[33]. Transport research funding in China is more concentrated in a few funding agencies compared to other countries. Looking at the funding acknowledgements of research publications as an indirect method of revealing funding support, the National Natural Science Foundation of China (NSFC), the Fundamental Research Funds for the Central Universities (FRFCU) and the National Basic Research Program of China (NBRPC) account for 6.5 % of all funded publications in transport worldwide in the top 10 funding sources acknowledged in publications during the period 2011-2015[34].

The Transport Planning and Research Institute (TPRI) is a relevant stakeholder in transport infrastructure research. TPRI is a public institution directly affiliated to the Ministry of Transport (MOT) of China and serves as a think-tank of the MOT in areas of policy, strategy, planning, technology, assessment, and theory. TPRI has been in charge of undertaking research for the major strategies and plans on transport infrastructure in China, including the "13th Five-Year Plan" for the Development of a Modern and Integrated Transportation System of China.

[33] https://www.journals.elsevier.com/transportation-research-part-b-methodological/news/how-chinas-research-is-fuelling-the-future-of-sustainable

[34] https://www.tandfonline.com/doi/full/10.1080/01441647.2016.1226693

5 Projects – quantitative assessment

An extensive quantitative assessment of transport infrastructure research projects can be found in a recently published TRIMIS R&I capacity report (van Balen et al. 2019b). The report analysed INF projects from different perspectives (geographical, transport mode etc.). These findings are limited to 127 H2020 projects (2014-onwards), nonetheless are indicative of the transport R&I state of play in Europe. The key findings indicate that:

- Spending on INF research under the H2020 framework programme peaked in the beginning of 2018.
- Road, rail and multimodal transport receive the greatest interest, while waterborne transport receives the smallest amount of funds for INF research amongst all modes.
- France and Germany are the largest beneficiaries of INF research funds. Organisations from Denmark and Sweden are relatively more successful in winning H2020 INF projects.
- An analysis on collaborations between MS identified strong ties and distinct gaps. Networking events and targeted linking could help organisations connect across Europe to deliver stronger H2020 proposals in the field of INF.

The reader is recommended to read the report for additional analyses, including geographical breakdown of FP spending, spending per different transport mode, and MS and corporate collaboration in FP research. The following sections provide a selection of these analysis, which for the purpose of this report have been updated to include the most recent data, and also cover FP7 projects.

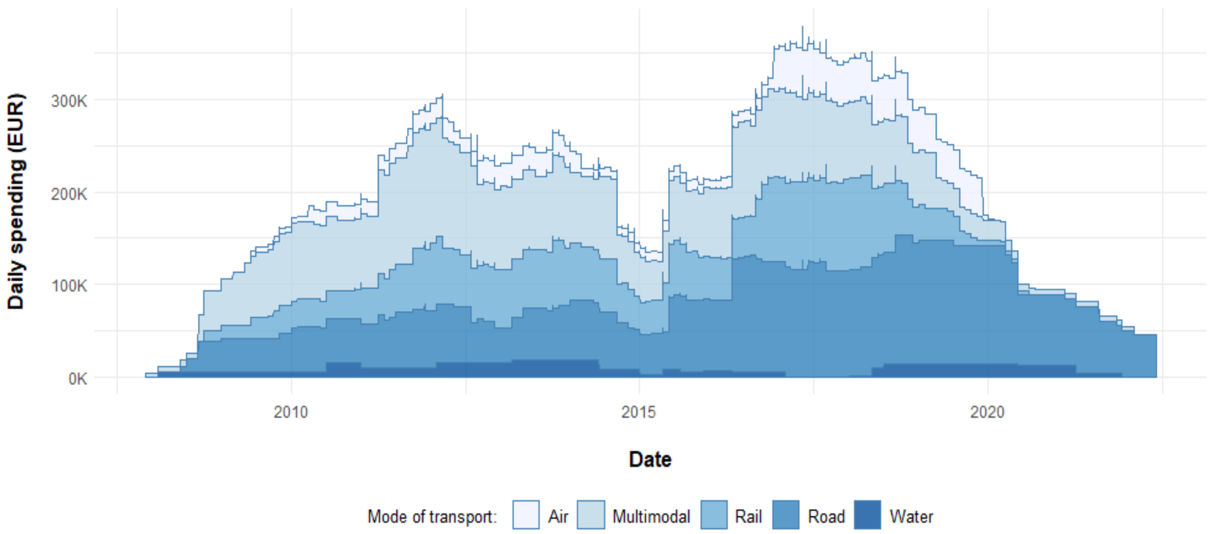
5.1 Transport infrastructure projects R&I spending

Under the last and current FP over € 1 061 million has been invested in INF research projects to date. This includes € 734 million of EU funding and € 327 million of own contributions by beneficiary organisations. The total investment under FP7 was € 563 million and around € 500 million has been invested so far under H2020. This amount is likely to grow as several funding calls are yet to be launched.

Figure 5 shows the average daily H2020 related spending for each transport mode since 2007. The figure rests on the assumptions that research spending is equally spread throughout a project's duration. By summing the spending of each project, the broader trends can be observed,

The daily research spending peaked in the first quarter of 2018 at approximately € 350 000. This peak can be partially explained by the timeframe of the FP, in which projects are selected between 2014 and 2020. The drop in financing in 2015 can be explained by FP7 projects that ended and H2020 projects that haven't started yet. This gap can be understood as a consequence of the FP based approach towards research financing.

Figure 5. Daily FP7 and H2020 INF R&I spending per transport mode



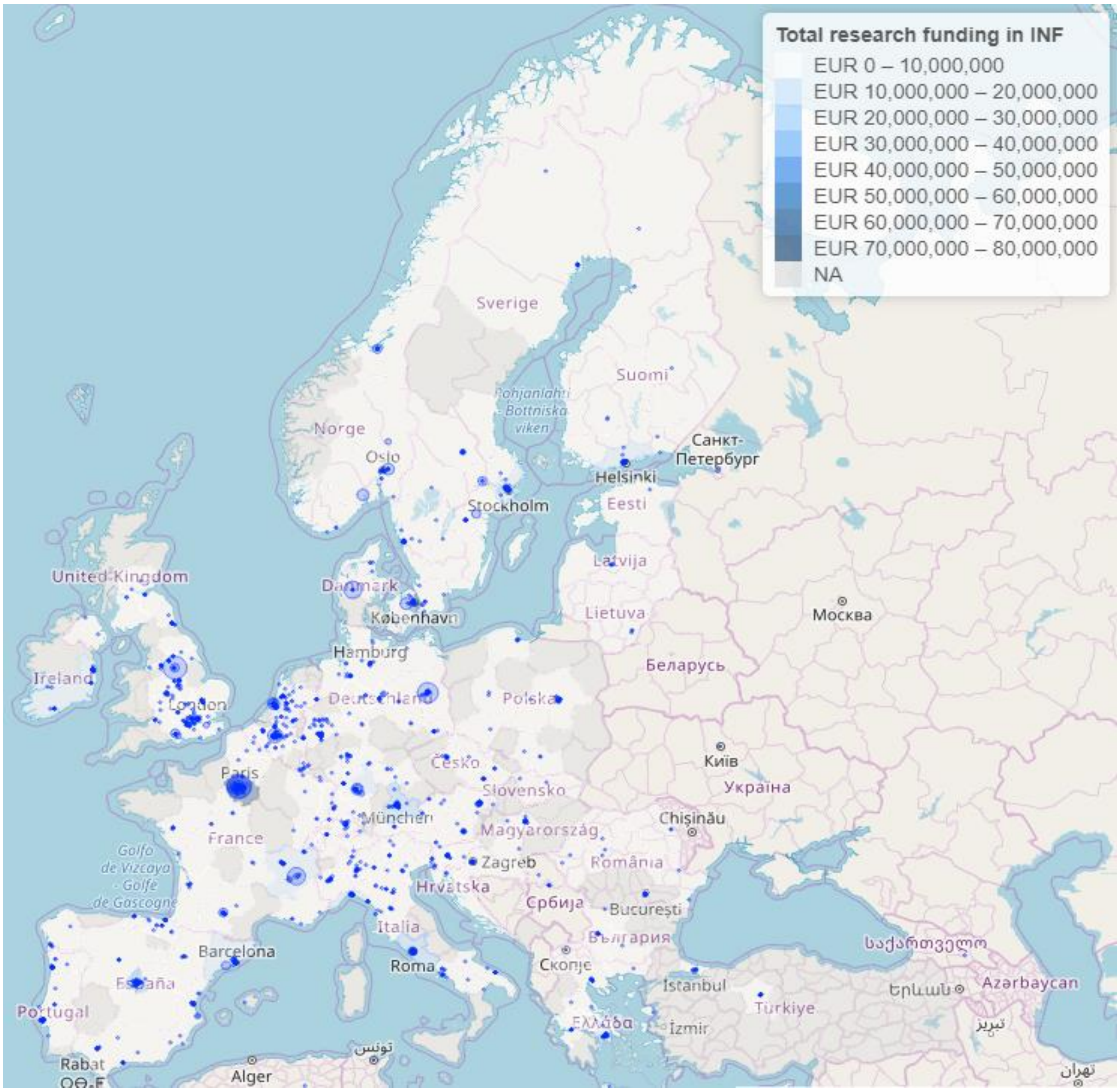
It is noticeable that the road and rail categories are relatively large. Research on air infrastructure is comparatively small while research on waterborne transport is very limited. Here it should be noted that aviation and waterborne related projects are also financed through other instruments, like CEF, which are not covered by this analysis.

5.2 Transport infrastructure projects geographical analysis

1478 unique organisations received funding for INF research, with an average of about € 474 000. Figure 6 provides a deeper look into the geographical spread of the funds. Several beneficiaries in the UK, France, Germany and Denmark receive a large part of the funding, as indicated by the size of the circles. Most organisations are located on the long stretch between Manchester and Munich. Organisations from the EU-13 receive a smaller share of the funds.

One remark is that the spending of research funds may happen in a different location than where a beneficiary is registered. Such could happen when pilot studies occur at different sites, which is not indicated below. Despite this limitation, it is believed that the map does provide a reasonable approximation of where resources are allocated.

Figure 6. Location of FP7 and H2020 INF funding beneficiaries



Source: TRIMIS elaborations

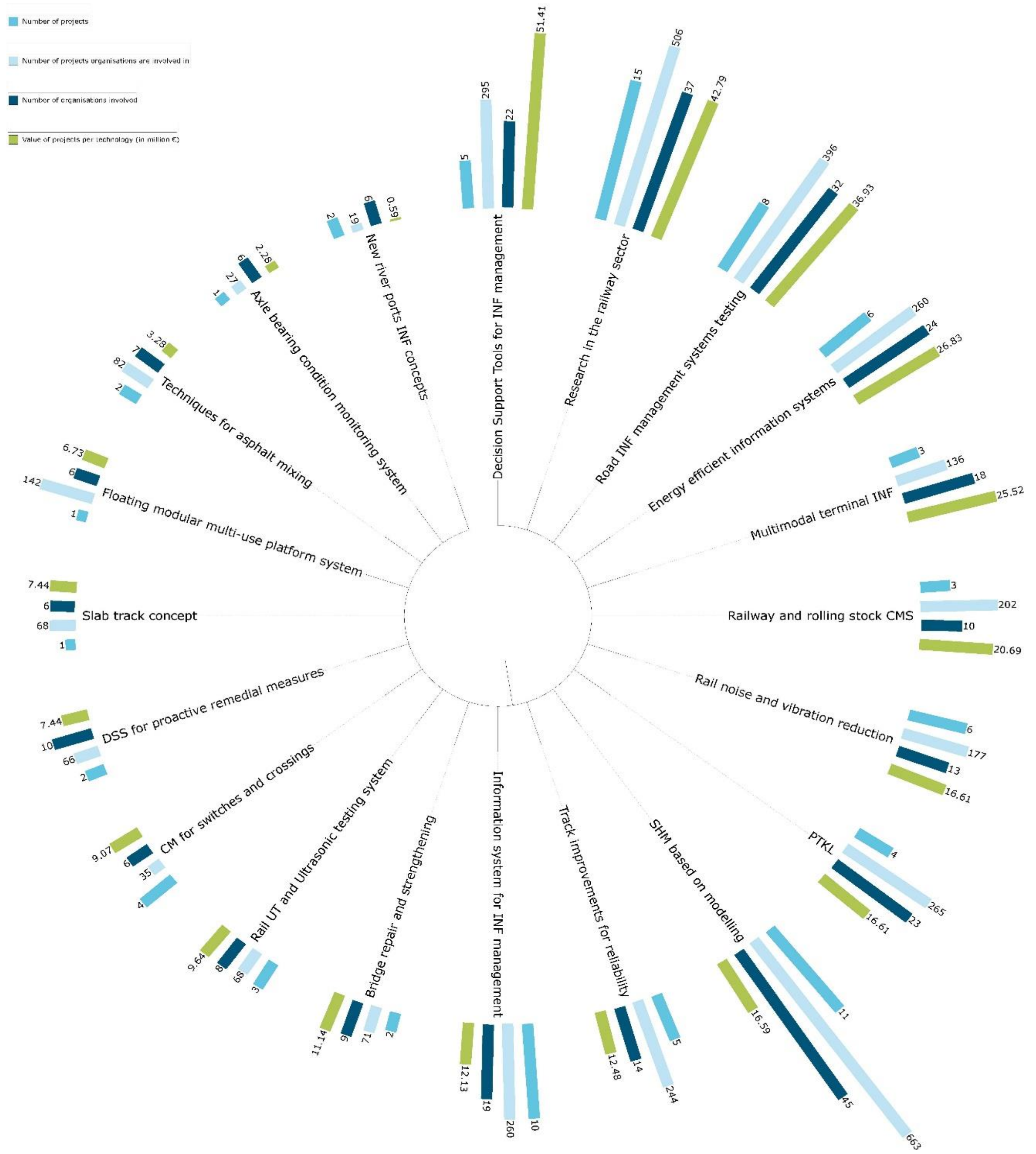
6 Technologies researched in framework programmes

This chapter provides a quantitative assessment of technologies researched in FP7 and H2020 projects in TRIMIS. The assessment is based in the methodology described in Section 2.2 and focuses on different monetary and technical indicators.

6.1 Technologies identified in the transport infrastructure roadmap

The analyses presented focus on the overall 'top 20' technologies identified for the transport infrastructure technologies roadmap. The radial structure of Figure 7 highlights the key metrics of the 'top 20' technologies.

Figure 7. Top 20 transport infrastructure technologies in FPs



Bars not in scale. Abbreviations: INF - Infrastructure; CMS - Condition Monitoring System; PTKL - Port and Terminal Knowledge Landscape; SHM - Structural Health Monitoring; UT - Ultrasonic Tomography; CM - Composite materials; DSS - Decision Support Tools

Source: TRIMIS elaborations

The figure is developed on the open and freely available interactive tree of life (Letunic and Bork 2019), a web-based tool for the display, manipulation and annotation of phylogenetic trees.

The metrics analysed in this case are:

- "Number of projects": the number of projects that have researched the technology;
- "Total budget": the total value of all projects that have researched the technology (i.e. the total investment, by both the EU and industry, in the development of the technology);
- "Number of organisations": the number of organisations that have been involved in projects that have researched the technology;
- "Number of projects organisations are involved in": the total number of projects that the organisations (identified as having been involved in projects researching the particular technology) have been involved in.

The first two metrics highlight the combined effort that has been put into the technology, while the third and the fourth proxy the level of interest in the technology in industry and academia, indicating the available capabilities to bring the technology to market.

The theme of decision support tools for infrastructure management has received the highest funding, followed by research in the railway sector. The latter though, sees a higher number of organisations involved and a (much) higher number of projects organisations are involved in. Road infrastructure management systems testing research completes the top-3 technology themes.

Although with limitations linked to the approach followed for clustering technologies in technology themes and building a taxonomy, the exercise of linking several technology metrics with organisational data, can be useful for identifying technology value chains, including opportunities, as well as providing indications on overspending and inefficiencies. In the future, efforts will be made to have a better coverage of technologies researched within projects, indexed in higher aggragation levels.

6.2 Technology development phases

In addition, the technology maturity was assessed for all technologies researched within the projects. The assessment is based on the technology readiness levels (TRLs), a method for estimating the maturity of technologies during the acquisition phase of a program, developed by the US National Aeronautics and Space Administration (NASA) in the 1970's.

Table 4 provides the description for each of the nine TRLs, as taken from Annex G of the Horizon 2020 work programme (2014-2015) [35] and the corresponding development phases used in TRIMIS.

Table 4. Technology readiness levels (TRLs)

TRL level	Description	TRIMIS development phase
TRL 1	Basic principles observed	Research / Invention
TRL 2	Technology concept formulated	
TRL 3	Experimental proof of concept	Validation
TRL 4	Technology validated in lab	
TRL 5	Technology validated in relevant environment	Demonstration/prototyping/pilot production
TRL 6	Technology demonstrated in relevant environment	
TRL 7	System prototype demonstration in operational environment	
TRL 8	System complete and qualified	Implementation
TRL 9	Actual system proven in operational environment	

Source: Horizon 2020 work programme (2014-2015), Annex G

[35] https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

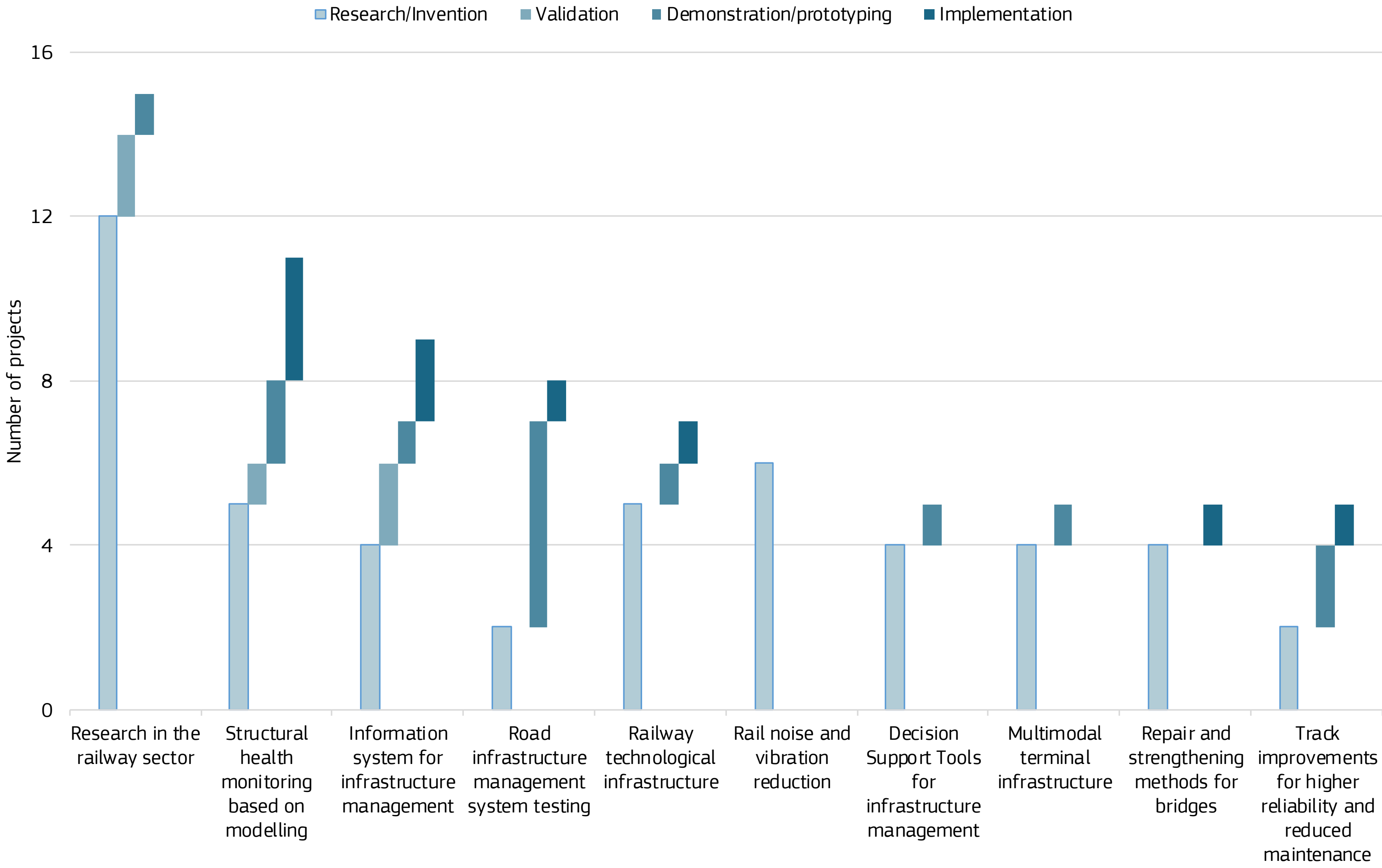
The European Commission advised that EU-funded research and innovation projects should adopt the TRL scale in 2010; TRLs were then implemented for the EU Horizon 2020 programme (Heder, 2017), although in practice TRLs are not consistently assigned to all Horizon 2020 projects. TRLs are based on a scale from 1 to 9, with 9 being the most mature technology.

As can be seen in Table 4, in TRIMIS, the nine TRLs have been consolidated into four development phases: research/invention, validation, demonstration/prototyping/pilot production, and implementation. These are used to monitor and describe the maturing of each technology in a similar way to the original TRLs.

Figure 8 reports the development phases of the Top 10 researched transport infrastructure technologies in FPs. Railway sector technologies (15) have been researched by the highest number of projects, followed by Structural health monitoring based on modelling (11) and Information system for infrastructure management (10). Only two out of the top 10 technologies have been researched over the entire development phase in FP.

Technologies for rail noise and vibration reduction are researched at a low development phase in FPs. Structural vibration heath monitoring based on modelling, information systems for infrastructure management and road infrastructure management system testing technologies, are researched also at a higher development phases, including implementation.

Figure 8. Development phases of the Top 10 researched transport infrastructure technologies in FPs



Source: TRIMIS elaborations

7 A text mining analysis on transport infrastructure

In order to have a notion of the prominent INF themes in R&I and academic research, two simple exercises have been performed, focusing on R&I in FP projects and academic research. For these exercises, 12 topics have been identified, expanding on the theme subdivision performed in Section 2.3. These topics are:

- Topic 1 “Pricing and charging”
- Topic 2 “Financing”
- Topic 3 “Multimodality, interoperability and interconnectivity”
- Topic 4 “Logistics”
- Topic 5 “Construction”
- Topic 6 “Maintenance”
- Topic 7 “Environmental concerns”
- Topic 8 “Safety and security”
- Topic 9 “User needs”
- Topic 10 “Resilience”
- Topic 11 ‘Technological changes in transport”
- Topic 12 “Communication and data transfer”

Topics 1 and 2 have a strong link to the “Pricing, taxation and financing” sub-themes, topics 3 and 4 to the “Intermodality, interoperability and integration of transport system” sub-theme, topics 5, 6 and 7 to the “Life-cycle optimisation of assets” sub-theme and, finally, topics 8 to 12 to the “Operation, efficiency and resilience” sub-theme. The sub-theme “Governance, planning and regulation” was much harder to assess with a simple text mining analysis.

7.1 Analysis on framework programme research

The goal of this exercise is to:

a. Identify main topics in infrastructure projects within FP.

b. See which topics are often mentioned together.

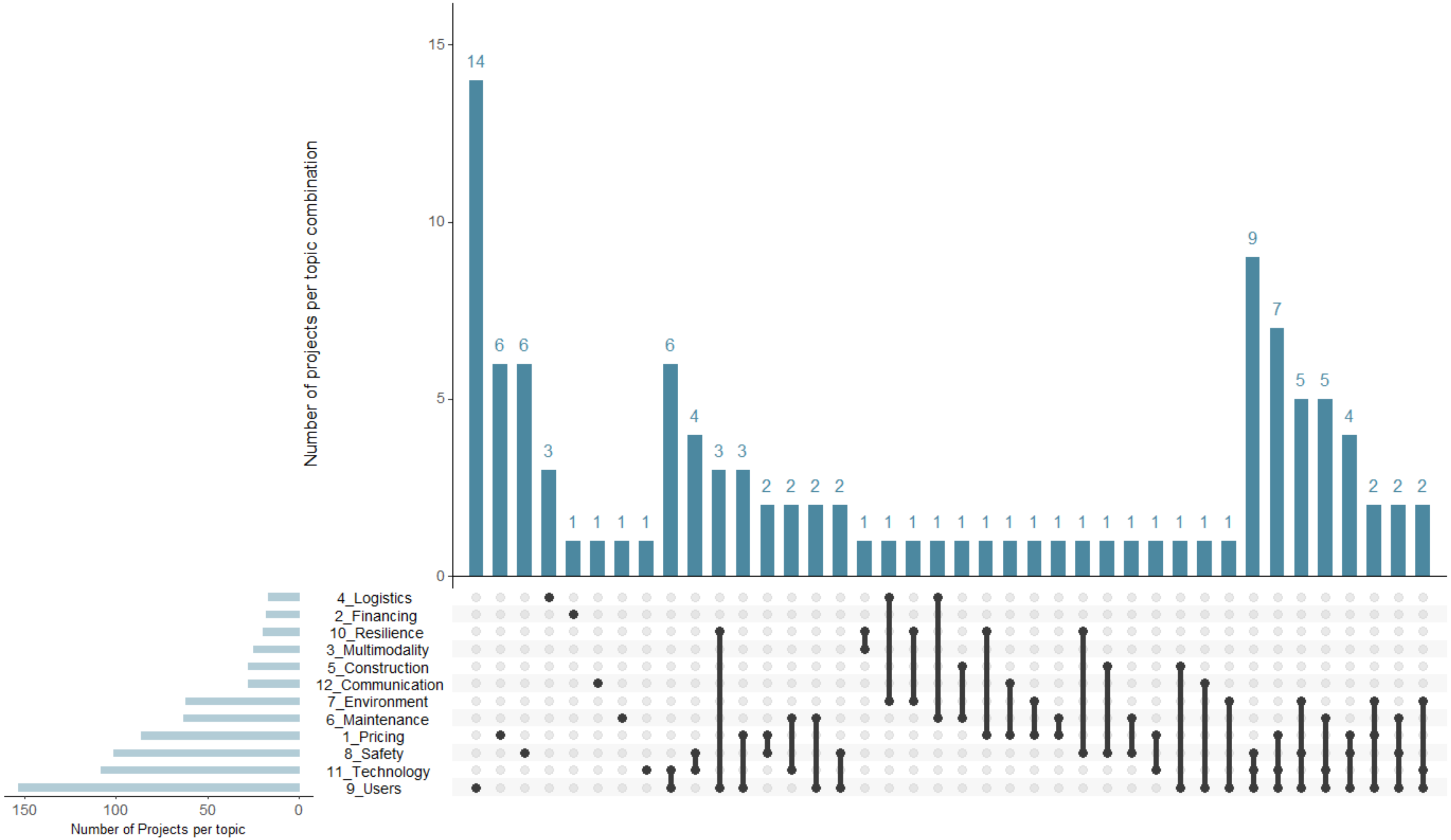
c. Identify potential gaps.

For each topic, a set of keywords or regular expressions (REGEX) have been identified (see ANNEX 2a).

The chart of Figure 9, based on 240 FP7 and H2020 projects in TRIMIS, shows how often the keywords of each theme were detected (left horizontal bars) in the projects’ objectives, and how often a certain combination of keywords occurred (vertical bars). The full chart extends considerably on the right side, but has been trimmed to fit in the page.

The chart provides a general idea of the prominent themes in the infrastructure projects in TRIMIS. As can be seen, ‘safety’, ‘technology’ and ‘users’ are the crosscutting keywords.

Figure 9. Text mining analysis on FPs



Source: TRIMIS elaborations

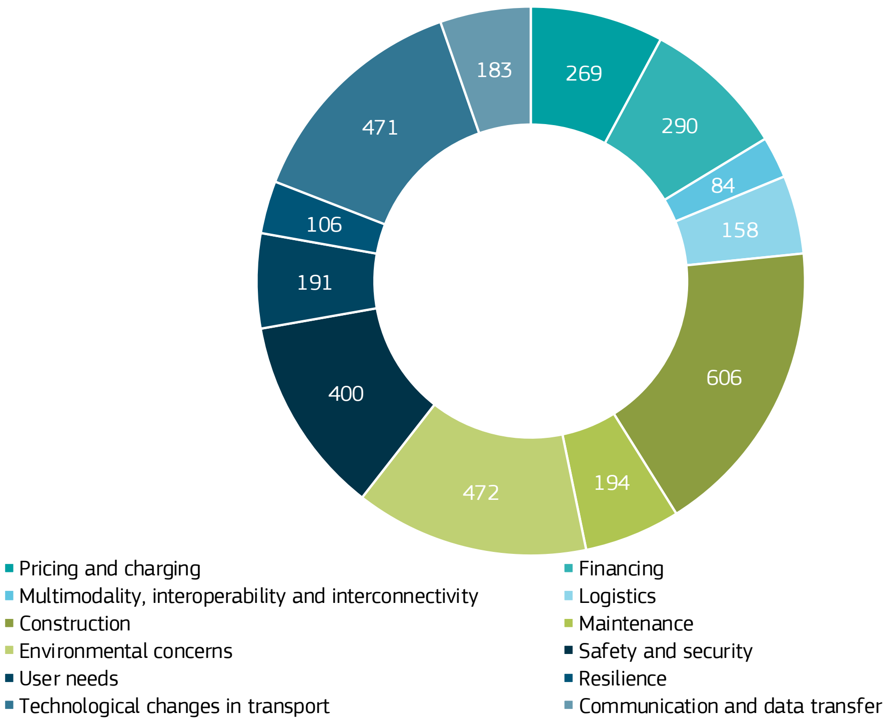
7.2 Analysis on scientific research

The Scopus citation database is the reference database for scientific research[36]. The following exercise has as objective to mark the evolution of peer reviewed scientific publications in the area of transport infrastructure research in the last 15 years, providing also a perspective beyond Europe.

For the exercise, a number of keywords and REGEX have been assigned to the 12 topics previously mentioned. The complete list of the queries used is reported in ANNEX 2b. Findings show that there is a vast international activity on all fronts for what regards infrastructure research. It appears that the US, the UK and China are leaders in this field, with strong presence also from other countries (Spain, Germany, Italy and France make it into the top 10).

Figure 10 shows the scientific production in the 12 topics in the last 15 years (2004-2018). Even though with limitations, the result highlights the role of construction research in this area.

Figure 10. Overview of transport infrastructure publications in the period 2004-2018



Source: TRIMIS elaborations based on Scopus data

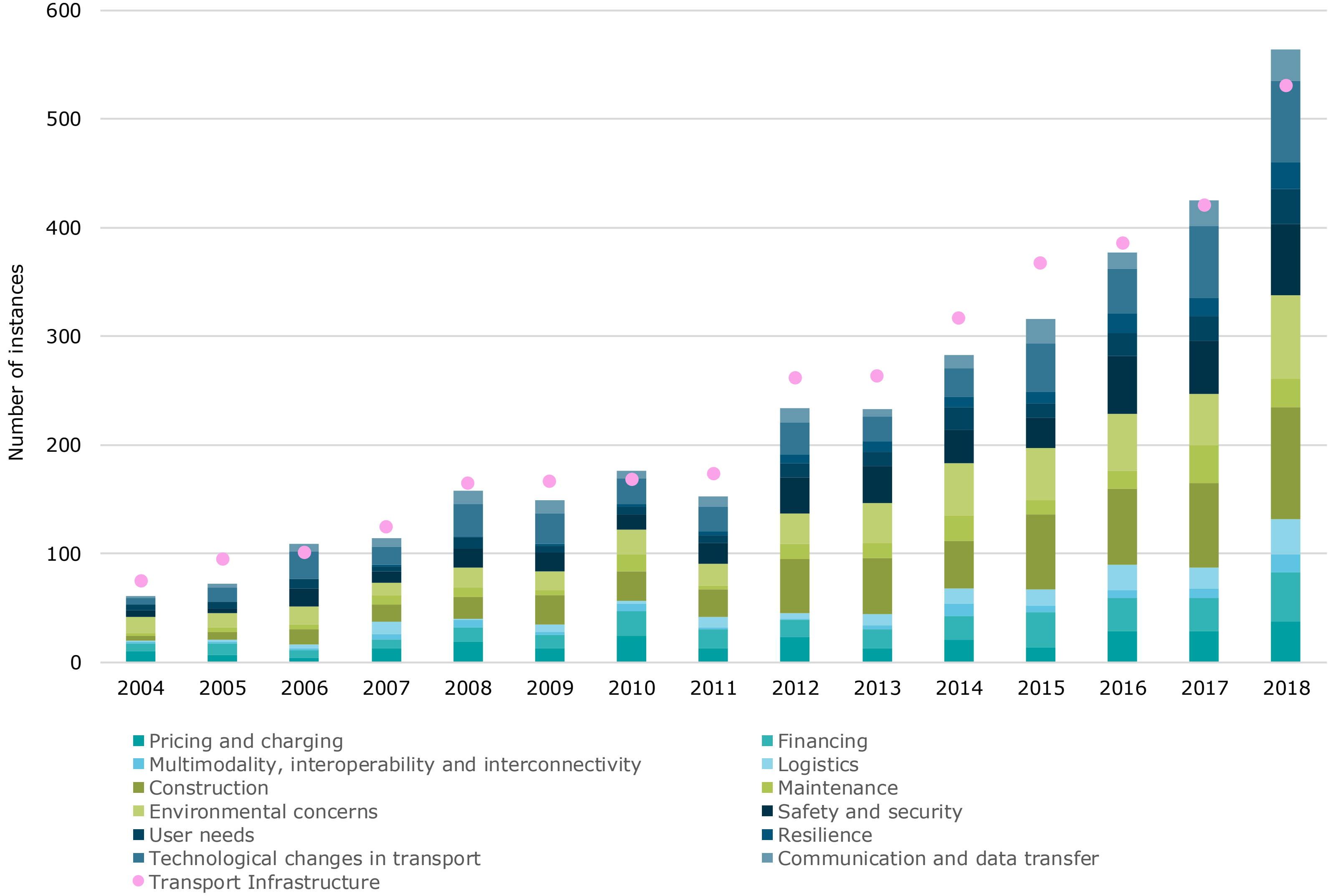
As Figure 11 suggests, an almost linear increase in transport infrastructure research on these topics can be observed, while in 2018 a significant increase can be observed. It should be observed that the number of publications in transport infrastructure in general (pink dots) has an increasing trend from year to year: starting from 75 in 2004, and rising to 531 in 2018. In some years, the number of papers in the 12 topics exceed the publications in transport infrastructure, meaning that there may be some overlappings (i.e. research papers addressing more than one topics). This is also a sign that the REGEX analysis provides satisfactory results.

Some other interesting findings:

- The word “resilience” first appeared in 2007 (in two papers).
- “Maintenance” and “technological changes” keywords increased significantly in the last two years.
- Likewise, research on “construction” seems to have increased in the last year.

[36] www.scopus.com

Figure 11. Transport infrastructure publications in the period 2004-2018



Source: TRIMIS elaborations

8 Research and Innovation assessment

Following a review of the research topics described in the draft roadmap document for the STRIA INF roadmap, the sub-themes presented in this report are:

- **Governance, planning and regulation**: This sub-theme relates to the research projects addressing the need for planning and regulation of the transport infrastructure.
- **Pricing, taxation and financing**: This sub-theme focuses on the projects researching the way that transport infrastructure is funded, particularly how it is funded and the parties responsible for the funding.
- **Intermodality, interoperability and integration of transport systems**: This sub-theme addresses the research into interaction across the transport systems and between transport modes.
- **Life-cycle optimisation of assets**: This sub-theme relates to the research projects addressing how the full life-cycle of assets is managed; this includes construction, maintenance and end-of-life of the infrastructure, along with the relationship with other infrastructure.
- **Operation, efficiency and resilience**: This sub-theme focuses on the projects researching how to ensure a robust and efficient infrastructure throughout its operation.

These sub-themes provide a comprehensive coverage of the aspects relating to the research projects within the Transport Infrastructure STRIA roadmap.

8.1 Sub-theme 1 – Governance, planning and regulation

In the context of transport infrastructure, governance should be regarded as the set of processes and results that, considering different public and private stakeholders, are oriented to achieve defined goals.

There are several levels of interconnections that affect decision-making processes in terms of European transport infrastructure, which is made more complex by the separation between management and administration of different transport modes. The complexity is compounded by the split between state-owned or privately regulated infrastructure and partially or fully unregulated private sector users or operators.

It is the role of governments and of governance systems to connect networks, policies and strategies at different levels to develop coherent transport policies. This is required if transport systems and transport infrastructure are to achieve the planned levels of decarbonisation. Good governance covering both public sector and private sector participants is required to incentivise both, to offer better operations and to work towards reducing the carbon emissions of transport. This can be achieved by means of providing the enhanced legal framework and supporting governments in the introduction of incentives.

8.1.1 Overall direction of R&I

The overall direction of the research and innovation in the governance, planning and regulation sub-theme is heading towards bringing together knowledge from different experts and sectors to effectively provide planning and regulation advice for different infrastructure types. This includes bringing together stakeholders from all transport modes and transport infrastructure sectors to deliver a shared European vision for infrastructure.

There is also research into crisis management, and how governments should respond in order to minimise the negative effects of the crisis. Examples of this include pandemics, as well as other natural or man-made disasters. In addition, with the rise of connected and autonomous vehicles, there is a need for planning and regulation to ensure their successful integration with the transport infrastructure. Therefore, there are projects researching this area, with the aim of providing policy and framework advice for safe and connected automation.

8.1.2 R&I activities

A selection of projects that have shown good examples of innovation in the governance, planning and regulation of European infrastructure are shown below. These projects have been chosen as they have either been completed recently, show well-reported results or have a high project value.

- REFINET (2015-2017) aimed to create a sustainable network of European and international stakeholders, including representatives from all transport modes and transport infrastructure sectors. The objective was to help to deliver a shared European vision of how to specify, design, build or renovate, and maintain the multimodal European transport infrastructure. The project also aimed at providing private and public decision makers with a set of recommendations and guidelines for strategic actions and required levels of cooperation between all stakeholders.
- Careful planning is needed in the event of a major crisis. PANDHUB (2014-2017) aimed to create an integrated toolbox to aid transport operators and relevant actors in major transport hubs in the development of their current pandemic and dangerous pathogen response plans. The objective of this project was to test the simulation of the spread of diseases and the evaluation of the effect of countermeasures, thereby providing information to major transport hubs to implement an efficient and rapid response to a cross-border incident. IMPROVER (2015-2018) aimed at improving European critical infrastructure resilience to crises and disasters through the implementation of social, organisational and technological resilience concepts to real life examples, including cross-border examples. The project aimed to provide much needed input to standardisation of the security of infrastructure.
- SCOUT (2016-2018) was aimed at identifying pathways for an accelerated proliferation of safe and connected high-degree automated driving in Europe, taking into account user needs and expectations, technical and non-technical gaps and risks, viable business models as well as international cooperation and competition. One of the main objectives of this project was to provide advice for policies and regulatory frameworks for safe and connected automation with the support of a network of relevant stakeholders.
- ALLIANCE (2016-2018) was aimed at developing advanced research and higher education in the transport field in Latvia by linking the Transport and Telecommunication Institute (TTI) with two internationally recognised research entries. Structured around three main pillars: organisation/governance, operational/services and service quality/customer satisfaction, ALLIANCE aimed at delivering a training program addressed to enhancing the knowledge of current and future researchers.
- BRIDGE SMS (2015-2018) highlighted the need for government agencies, public and private sectors and professional engineering sectors across Europe to come together and proactively meet the challenge of creating a climate resilient infrastructure system. The BRIDGE SMS project aimed at developing an open-source cloud based intelligent decision support system for the assessment and management of the hydraulic vulnerability of bridges over water.
- The project SMARTV2G (2011-2014) focused on connecting EVs to the electricity grid, monitoring the energy flows and their efficiency from a safety perspective. The idea was to create a system that allows for the EV to work as an energy storage system that can be utilised by the grid when the vehicle is not being used. This requires an advanced system of communication, automation and control of the information and the energy used.

8.1.3 Achievements

Several projects have improved on current-state-of-the-art in the research area of governance, planning and regulation. The results and achievements of these projects are presented below.

The REFINET project helped to create a systematic exchange of information and sharing of results across Europe. The project gathered together various stakeholders from different profiles and expertise involved in increasing complex infrastructures and services, therefore helping to improve the coordination of best practises and innovation between stakeholders across different transport modes.

PANDHUB developed Information Technology tools for rapid data collection and sharing in the event of a major disease breakout. Evidence-based practical guidance for the protection of people was also drafted, with detailed instructions of how to minimise the risk of contracting an infectious disease in a crowded transport hub. Additionally, a decontamination and disinfection guide described suitable cleaning methods for various types of contamination.

SCOUT concluded that there are many technical and non-technical challenges for connected automated driving, and many actions require the outcome of others before they can start. This indicated that there may be a large delay in delivering self-driving cars if their implementation is not well coordinated. The roadmap developed by SCOUT focused on specific use cases and well-defined milestones. Examples of such use cases were automated on-demand shuttles and delivery robots. It is expected that these roadmaps will add cohesion and insight to building a common European innovation strategy for connected automated vehicles.

ALLIANCE successfully developed an educational and training program in the field of sustainable transport. Based on this program, partners developed digitalised courses to support learning purposes. The TTI significantly improved collaboration in project theme areas, by organising five research international teams consisting of young and senior researchers. This activity raised the number of publications produced by TTI staff.

The new standardised bridge inspection method developed in BRIDGE SMS was piloted on two river catchments in County Cork, Ireland and further testing of the system was carried out on bridges in Croatia and Portugal. The full product is nearly market ready, with certain customisation required for new users. Two industry partners in Ireland and Portugal are already using first versions of the tool. The team is still working to improve the product, and a spin-off company has been set up at the University of Zagreb.

EVs can be used as an energy management system for the grid, which requires careful management and planning to incorporate. The project SMARTV2G found that EVs could be used for storage for direct current charging, but only partially under alternating current charging due to standardisation limits. The systems allowed for users to sell the energy that they do not use back to the electricity grid. Another innovation from the project was a mobile phone application that allows users to receive information on vehicle battery conditions, and to locate the nearest charge point and reserve it for a specific time.

8.1.4 Implications for future research

The BRIDGE SMS project highlighted the need for government agencies, public and private sectors and professional engineering sectors across Europe to come together and proactively meet the challenge of creating a climate resilient infrastructure system. This resulted in the development of a standardised bridge inspection method, which is nearly market ready. The project results state that customisations are required for new users of the system. New research could be focused on creating a uniform system, which does not require any modifications for new users, this would help with the full commercialisation of the product and bring a standardised bridge inspection method to Europe.

There has been significant funding awarded to projects dealing with crisis management, including developing a standardisation of security of infrastructure and tools to provide advice in the event of a pandemic. Whilst these projects have provided good results, further research is needed to develop a common European tool for the assessment of transport infrastructure vulnerability in natural or made-made disasters. This has resulted in the call for proposal in H2020 research programme to create a consolidated, common European understanding of disaster resilience. Further to this, a recommendation from the PANDHUB project was for transport operators to consider using social media platforms to rapidly distribute/obtain information to/from members of the public during an infectious disease outbreak. Testing of this methodology would need to be researched and the results carefully considered as rumours can easily be spread on social media.

The majority of transport infrastructure projects are appraised on the basis of individual projects, and the emphasis is on economic factors. Decarbonisation should be considered as a key variable for the planning process, both at project level and at a higher transport policy level. Research investment should be considered for developing infrastructure project appraisal tools, applicable to all kind of transport infrastructure, that prioritise alternatives promoting decarbonisation, not only for the infrastructure itself, but also for use through the whole life-cycle.

8.1.5 Implications for future policy development

The project SCOUT identified several pathways for a safe and connected automated driving in Europe and showed that for a successful implementation of autonomous cars, careful planning and coordination is required. With amendments to the 1968 Vienna Convention on Road Traffic being required for automated driving, the project also identified major legal and regulatory milestones towards deployment of these vehicles. When developing European policy for the wide-spread uptake of autonomous vehicles, the milestones attained from the SCOUT project should be carefully considered.

Results from the PANDHUB and IMPROVER projects relating to crisis and disaster management have led to a H2020 call for proposals on creating a consolidated, common European understanding of disaster resilience. If successful, incentives could be given to ensure that a common European management policy is in place to effectively and efficiently manage transport infrastructure in the event of a natural or man-made disaster.

8.2 Sub-theme 2 – Pricing, taxation and financing

Pricing has traditionally been acknowledged as one of the most effective incentive mechanisms on users to take decisions according to wider social interests. As emitting CO_2 gets more expensive for transport operators, they are incentivised to switch to cleaner fuels, acquire greener vehicles and make a better use of the capacity provided by both vehicles and infrastructure. Pricing is also used to incentivise users to spread peak hour demand, thereby reducing congestion and delay, and so further reducing CO_2 emissions.

Due to the finite amount of investment available for transport infrastructure, there is a need to optimally manage and govern infrastructure projects in order to ensure the best possible return from investment. There is also a need for the funding and financing schemes to be assessed to see if the project costs and time constraints will be met. Innovative financing schemes and business models could help towards maximising the public funding in transport infrastructure. Optimising the limited public resources and making sure that full revenue is generated is key for future investment in transport infrastructure.

8.2.1 Overall direction of R&I

The overall direction of the research in the pricing, taxation and financing sub-theme is towards establishing common European frameworks for governance, management and finance of transport infrastructure projects to ensure the best possible return from limited investment funds in the transport infrastructure. The research is looking into the optimal way to assess funding schemes for investments in infrastructure.

There is also research and funding going towards managing fare avoidance on public transport. This fare avoidance can be detected using smart technologies and inspectors alerted in real-time. This research could greatly reduce the amount of fraud on the public transport system.

8.2.2 R&I activities

A selection of projects that have shown good examples of innovation in the pricing, taxation and financing of European infrastructure are shown below. These projects have been chosen as they have either been completed recently, show well-reported results and have a high project value.

- 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.

- INFRAVATION (2014-2018) brought together funding from 11 countries, which totalled around € 10 million, with the aim of funding research projects to accelerate the application of promising innovations in the construction and maintenance of roads and bridges. The innovations have been delivered at up to TRL 7, meaning that has been tested and demonstrated in real-world settings. Aside from collecting funding, the project also aimed at pooling skills, know-how and expertise for transnational collaborations.
- The overall objective of RAGTIME (2016-2019) was to establish a common framework for governance, management and finance of transport infrastructure projects in order to ensure the best possible return from limited investment funds in transport infrastructures. RAGTIME aimed to develop, demonstrate and validate an innovative management approach and to lay out a whole system planning software platform, based on standard multiscale data models, able to facilitate a holistic management throughout the entire life-cycle of the infrastructure. It proposed a shifted from "conditinon" approach to "risk" approach.
- TRAINSFARE (2017-2019) was aimed at tackling fare evasion on public transport. The innovation is a highly precise and effective support tool that detects frauds at barriers and alerts ticket inspectors in real time via a mobile app for immediate action. The feasibility study was funded and developed under a SME (Small Medium Enterprise) Instrument Phase 1 grant; TRAINSFARE is Phase 2 of the project and focused on the scale up and implementation of the technology.

8.2.3 Achievements

Several projects have improved on current-state-of-the-art in the research area of pricing, taxation and financing of European infrastructure. The results and achievements of these projects are presented below.

The study and research conducted within BENEFIT led to the conclusion that appropriate low-cost financing schemes are needed. A key outcome of the project was the development of the Transport Infrastructure Resilience Indicator (TIRI) rating to be used to provide project life-cycle assessments concerning the likelihood to reach cost and time targets in relation to construction completion, traffic and revenues. The TIRI also allows for assessing the managerial flexibility throughout the project life-cycle, guiding possible improvements and the effective use of alternative options. The results from BENEFIT can be applied to multiple transport infrastructure projects to aid with the financing aspects of the infrastructure.

The project INFRAVATION (2014-2018) received 103 proposals for the funding pot, which was filtered down to the nine best quality proposals. From these proposals, some projects succeeded in finding test sites to scale up their innovations. Collaborations between some of the projects have also continued after the completion of the projects, and a number have already exploited the innovations commercially. One of the INFRAVATION projects, SUREBRidge, was aimed at preserving relevant structural bridge elements, whilst refurbishing and strengthening the bridge to the desired service level using bonded fibre reinforced polymer (FRP). This project is implementing a case study to assess the application of the technology to a real bridge. Another project, SHAPE, has developed a device to monitor the vibrations of a road bridge in real-time. The project is aiming at further developing a cloud-based approach to provide a centralised data management and analysis system for the long-term monitoring of bridges.

RAGTIME (2016-2019) developed an advanced asset integrity management framework, which focuses on defining technical, legal and economic requirements. Further development of this framework resulted in the development of tools and interconnected modules (governance, financial, economic & risk and technical management) integrated on a cloud-based platform. Finally, the advanced asset integrity management framework was demonstrated and validated for three case studies. The results were validated against the UK case study; results were benchmarked in a viaduct-based case study in Italy, and in a railway-based case study in Slovenia.

TRAINSFARE aimed at bringing their fare evasion detection technology to market. The technology is based on a highly precise and effective system that detects fraud at barriers using video streams, and alerts ticket inspectors in real time via a mobile app so that they can act immediately. During the first 12 months of the project, first pilot tests have been conducted with a European transport operator, with second and third tests planned for the near future. So far, the project has allowed for attendance at professional exhibitions and forums to showcase the technology. This has significantly increased the visibility amongst public transport operators.

8.2.4 Implications for future research

Paying for the use of transport infrastructure, and how the payment is accepted, represents large amounts of income for public and private bodies. In Germany, the LKW Maut (a toll for goods vehicles) generated € 4.34 billion (over 80 % of total revenue) for the Federal Ministry for Transport and Digital Infrastructures in 2014[37]. Similarly, many public transport operators acquire a large majority of their income through fares. For example, in the financial year 2019/2020, Transport for London (TFL) is predicted to make 47 % of their total income from fares[38]. Therefore, it is critical that, for public transport operators to continue running and improving their service, fare and toll avoidance must be addressed. Pilot tests have been conducted with a European transport operator, and the results from TRANSFARE are expected to greatly reduce the amount of fraud on public transport. In order for this technology to reach the highest development phase and achieve market roll-out, more research and testing is needed to assess the commercial viability of the product.

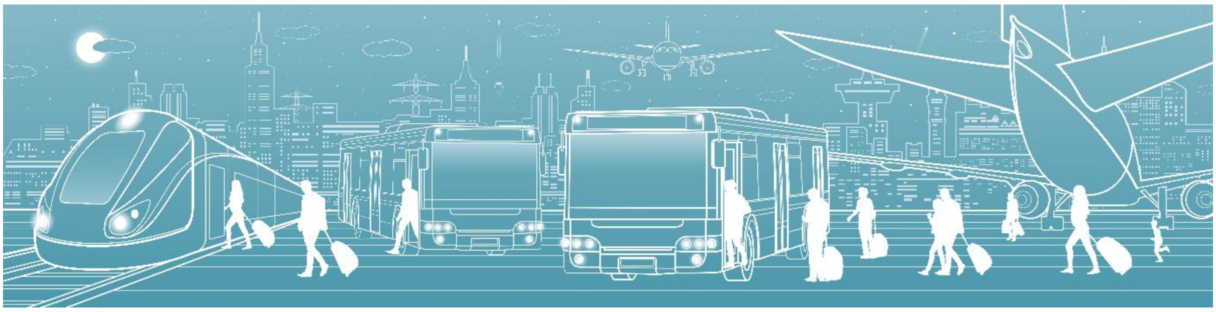
There have been projects researching the optimal way to manage and govern infrastructure projects to return the highest possible investment, namely RAGTIME. The results from this research will certainly attract the attention of investors, as they will likely want the best return given the current limited public budget for transport infrastructure projects (and public funding as a whole). RAGTIME demonstrated and validated the cloud-based platform management framework on three case studies. In order to raise the development phase of this technology to implementation, the results from these case studies should be assessed and further optimisation of the tool undertaken. This will prove the value of the management framework and help with the roll-out of the technology.

8.2.5 Implications for future policy development

The project RAGTIME researched into management and financing of infrastructure projects with the aim of maximising the return on investments, as well as managing the holistic life-cycle of the infrastructure. This project developed an asset management framework to aid with defining technical, legal and economic requirements for transport infrastructure. This framework was demonstrated by three case studies across Europe. European policy should reflect the achievements of this project, with all new research projects that receive funding being required to have financial assessment over the entire project life-cycle. This would help with optimising rate of return on investment, as well as efficiently managing the project.

The creation of independent funding pots focusing on a specific area of research has shown promising results. INFRAVATION was a good example of one of these projects, which has supplied funding to nine high-quality project proposals. Accumulating the pot, and then assessing the proposals to select only a few high-quality proposals is a good strategy for planning and financing specific research areas. A similar financing strategy could be proposed for future European transport infrastructure projects.

8.3 Sub-theme 3 – Intermodality, interoperability and integration of transport systems



Intermodality, interoperability and integration of transport systems have been high on the European policy for several decades. Since the concept first appeared, the idea of integration of transport systems evolved from

[37] Transport & Environment; The economic impacts of road tolls, 2017.
[38] Transport for London; https://tfl.gov.uk/corporate/about-tfl/how-we-work/how-we-are-funded

the integration of physical networks to the integration among multiple transport modes and the integration of transport systems. The following descriptions have been defined in the context of this sub-theme assessment:

- Intermodality refers to the seamless transportation of freight or passengers through multiple modes of transport under a single form of organisation and/or billing.
- Interoperability is the (technical) ability of a passenger, transport operator, vehicle or other means of transport to operate seamlessly on multiple networks or parts of networks, that could be physical, digital or financial.
- Integration of transport systems refers to the overall process of treating transport modes in terms of infrastructure, coordination, information sharing, billing, accessibility etc. as one.

Improvements in this sub-theme would help achieve decarbonisation policy targets by allowing for a shift to the most appropriate transport mode. This would reduce congestion, improve the efficiency and improve coordination in the use of transport infrastructure.

8.3.1 Overall direction of R&I

There is significant research and funding for projects aiming to develop better understanding across transport modes in terms of infrastructure. It has been realised that, for improved intermodality, it is necessary to share experiences and common challenges across the infrastructure of various transport modes. Another major area of research in infrastructure is cross-border technologies, with projects researching consistent incident management across Europe. Cross-border technologies also researched focused on identifying 'high-risk' passengers which could be seen as a sensitive issue. The idea of this research is to efficiently process the 'low-risk' passengers whilst focusing resources on the 'high-risk' passengers.

With the rise of autonomous vehicles, there is a need to create a European standard for infrastructure requirements across the Member States, which is also attracting research attention. Innovative solutions are also looking into how ride sharing can be integrated with the existing transport infrastructure, increasing the intermodality and interoperability of urban transport.

8.3.2 R&I activities

A selection of projects that have shown good examples of innovation in the intermodality, interoperability and integration of transport system of European infrastructure are shown below. These projects have been chosen as they have either been completed recently, show well-reported results or have a high project value.

- USE-IT (2015-2017) had the objective of creating a better understanding of the common challenges experienced across transport modes. The project aimed to bring representatives of transport modes together to share experience and skills and to develop a set of common research objectives which will address challenges faced by the multiple transport modes. The project drew upon experience gained from the Joint European Transport platform with the focus on infrastructure operations, and also focused on research objectives presented in the Forever Open Road programme and the work of the FORx4 – Forever Open Road, Railway, Runway and River – a cross-modal transport initiative for research.
- FOX (2015-2017) was the sister project of USE-IT and aimed to develop a highly efficient and effective cross-modal research and development environment meeting the requirements of transport and connectivity. The FOX project aimed to identify common needs and innovative techniques in the areas of construction, maintenance, inspection, and recycling & reuse of transport infrastructure. This was reached by the involvement of all stakeholders (owners, researchers, and industry) of the four transport modes (road, rail, water and air).
- There are projects researching advanced cross-border security technologies. PROTECT (2016-2019) aimed to demonstrate an enhanced biometric-based person identification system that works across a range of border crossing types. The technology was to be demonstrated at two different border crossing sites. The ability for the system to efficiently process low-risk travellers, combined with increased levels of accuracy, security and privacy standards and enabling border guards to concentrate resource on higher-risk travellers, were central ambitions of the project. ECOSSIAN (2014-2017) had objectives to support a pan-European early-warning system through the connection of Member States to a European security operation centre, including the required

interoperability standards. An aim was also to enable consistent and collaborative cross-border and cross-sectorial incident management for critical infrastructure.

– SocialCar (2015-2018) was a research and innovation project that was aimed at incorporating carpooling into existing mobility systems; by means of powerful planning algorithms and big data integration from public transport, carpooling systems, and crowd sourcing. The project united ITS developers, social and economic scientists, transport engineers, carpoolers and public authorities from various European countries. The overall objective of SocialCar was to design, develop, test and roll-out a service that simplifies the travel experience of citizens in urban and semi-urban areas.

8.3.3 Achievements

Several projects have improved on currentstate-of-the-art in the research area of intermodality, interoperability and integration of transport system of European infrastructure. The results and achievements of these projects are presented below.

USE-IT developed a roadmap detailing the research strategies and implementation stages to ensure greater co-modal cooperation on customer, safety, security and energy matters. One of the key outputs of the project, the development of multimodal research calls, will be used as an investment plan to both research funders and as an investment strategy document for public and private infrastructure owners, operators and contractors. Similar results were achieved in the sister project, FOX. This will greatly aid the intermodality of new transport research projects.

The results from PROTECT include researching, developing and documenting new concepts and processes for less intrusive, faster, usable, accurate and secure biometric border identification systems. This has led to the design and development of the first version of the PROTECT system architecture and border guard interface. From the ECOSSIAN project, the system components for incident information collection, sharing, analysis evaluation and visualisation were developed and tested, with necessary interfaces for the integration defined. In addition to this, a secured data storage component was implemented. The ECOSSIAN system had three national demonstrations of which one concerned transport infrastructure and a pan-European demonstration which showed the capabilities of the integrated ECOSSIAN framework at operational, national and European levels.

SocialCar developed a ridesharing app, which has been tested in 10 European sites. This software has now been successfully rolled out and is an example of a research project that has started out in the research/invention development phase and became fully implemented by the end of the project. SocialCar matches travel requests with the integrated public-private transport supply, therefore advancing technologies in the intermodality, interoperability and integration of transport systems.

8.3.4 Implications for future research

The projects PROTECT and ECOSSIAN researched cross-border technologies. The PROTECT system has been developed, and further funding could be allocated to raise the development phase of the technology further. This would help to advance the cross-border identification process and allow for improved data and system interoperability across Europe. The ECOSSIAN project resulted in a cross-border incident sharing system demonstrated across three nations as well as across Europe. With the capabilities of this technology now demonstrated, further research in how to implement the ECOSSIAN framework is key.

There is a need to integrate multimodal transport in urban areas, which is researched in the project SocialCar but more is needed to address this challenge. This will require close management of all transport systems (road, rail, bus, etc.) under the strategic command of one transport authority. The authority can then prioritise between the different transport modes and introduce standard charging and ticketing systems across the full network to simplify use. Further research into this area of intermodality and interoperability is needed with the upcoming technological advances in MaaS.

There has not been much research into the effects of using unconventional transport systems for freight. With the recent advances in drone technology it is a real possibility that they could be used for the transportation of goods, particularly in urban areas. This will require research and careful planning into how this innovation will integrate with the other transport systems. There is also a risk that using drone technology to solve problems of road congestion and speed of delivery could increase the carbon consumption and interfere with the aviation sector. These issues will need to be addressed in the uptake of drone transport.

For the mass uptake of electric vehicles, interoperability, both technical (plug) and payment, between electric charging points providers is key. Individual EU Member States formulate targets and incentivise the deployment of charging infrastructure in accordance with Directive 2014/94/EU (Alternative Fuels Infrastructure Directive), which may lead to a lack of standards across EU wide charging infrastructure. Creating uniform electric charging infrastructure across Europe in terms of pricing and accessibility would increase the wide-spread uptake of EVs. Users would benefit from being able to charge at any charge point across Europe, using the same payment method. This would reduce range anxiety, a key reason why some users will not drive electric vehicles.

8.3.5 Implications for future policy development

To improve the intermodality, interoperability and integration of the transport system across Europe it is key to create policies that apply to all Member States. This is true for the cross-border research which has been conducted in the ECOSSIAN project. Creating policy that will allow for the implementation of the data and incident sharing technology across Europe will help to ensure the uptake of the technology.

Intermodality, interoperability and integration of the transport system will be vital to achieve transport decarbonisation across Europe and support new mobility services. Research in this sub-theme would help to drive the shift to the most appropriate transport mode, hence reducing congestion and improving efficiency of the transport infrastructure. The SocialCar project developed and rolled-out a ridesharing mobile application, which can offer this reduced urban congestion. Local authorities should raise awareness and encourage the use of this application within the urban environment. The reduced congestion will have benefits towards both decarbonisation as well as reduced air pollutants.

A wider European policy for interoperable electric charging networks would greatly aid the uptake of electric vehicles. This would have benefits in terms of air quality emissions as well as decarbonisation as the electrical grid becomes cleaner in the future. Further research is needed to assess the impacts of this interoperability between electric charging network providers.

8.4 Sub-theme 4 – Life-cycle optimisation of assets

Many transport infrastructure owners recognise the importance of optimising the cost of infrastructure over the full life-cycle, although not many are in a position to manage the environmental cost over the full operational life. Incentives within transport mean that new infrastructure is often financially cheaper and easier to deliver than a large-scale upgrade of existing infrastructure, but with greater environmental impact. Due to innovation, construction technologies are appearing that allow longer component life between maintenance interventions. These systems are also supporting the use of more predictive maintenance, offering less disruption to users and therefore improving the efficiency of the transport infrastructure.

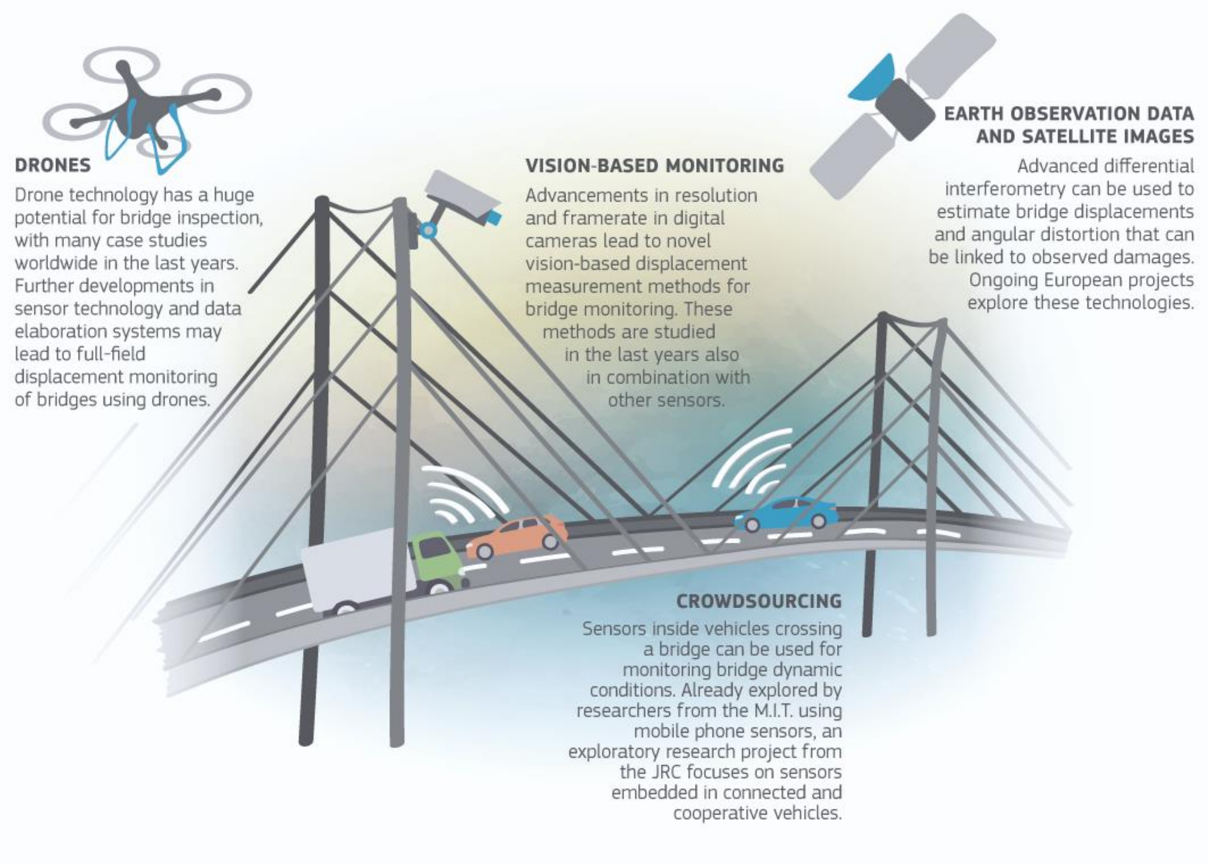
8.4.1 Overall direction of R&I

There is a significant number of projects researching life-cycle optimisation of assets. This is broadly split into construction, maintenance and environmental concerns. SHM is receiving considerable research attention and is a key area for future maintenance innovations. This is because new innovations have the ability to improve safety whilst also reducing maintenance cost, making it an attractive area of research. The SHM activities can span across multiple transport modes and are largely focused on infrastructure such as bridges and railway infrastructure.

Due to new autonomous technologies, there can be improvements in terms of efficiencies and cost reductions in both the construction and maintenance phase of infrastructure. Many automated monitoring systems are being developed and tested, relying on automatically detecting structural failures hence reducing the time and cost spent on manual maintenance.

Focusing on SHM, a recent report on bridge maintenance, inspection and monitoring R&I in Europe (Gkoumas et al. 2019), assesses more than 40 EU funded projects, discusses the transition of technology from research to market and identifies new solutions and technologies that are being explored. Figure 12 provides in a graphic way some promising new methods and technologies.

Figure 12. Promising bridge SHM methods



Source: Gkoumas et al. 2019

Some of the emerging methods focus on novel technologies, for example use of drones (two projects already under the H2020 programme), Earth Observation data from Synthetic Aperture Radar (SAR) satellites (I.MODI F2020 SME Instrument Phase 2 project[39]), crowdsourcing and fast speed cameras.

The MITICA (Monitoring Transport Infrastructures with Connected and Automated vehicles) 2-year Exploratory Research project by the JRC starting in the end of 2019, will investigate the feasibility of indirect Structural Monitoring (iSHM) from on-board sensors measurements of connected vehicles integrated with infrastructural monitoring systems (V2I communication) to assess the structural condition of infrastructural assets. Exploratory Research is included as a direct action in H2020 for the JRC to pursue excellence[40].

Finally, the projects within life-cycle optimisation of assets tend to be further along the development phases, with pilot tests and implementation of projects being common.

[39] http://www.imodi.info/en/home-en/

[40] https://cordis.europa.eu/programme/rcn/664511/en

8.4.2 R&I activities

A selection of projects that have shown good examples of innovation in the life-cycle optimisation of assets of European infrastructure are shown below. These projects have been chosen as they have either been completed recently, show well-reported results or have a high project value.

- COBRI (2015-2017) was aimed at developing and implementing a fully functional model of a hand-held non-destructive testing/evaluation instrument. The objective is to simplify and improve current bridge inspection methods and consequently improve safety, enhance capital investments and road infrastructure capacity. The instrument was validated in a field test.
- Real-time live condition monitoring of rail track is not currently available, and the project WARNTRAK (2015-2017) aimed at improving a track monitoring system and raising the technology development phase up to pilot testing and prototyping. The low-cost self-contained wireless sensors are easily fitted and are expected to deliver major benefits through cost reductions of rail track maintenance as well as improved train safety and operational reliability.
- SmartSite (2015-2017) has the objective to address the problem of avoidable faults in the field of road construction, and in particular in the production of cover layers. SmartSite aimed to develop a highly efficient, open and flexible platform for intelligent autonomous construction equipment and systems, intelligent autonomous construction site networks and environments, and intelligent building process control. By developing these subsystems, the project aimed to streamline and automate key parts of the road construction process.
- SENSKIN (2015-2018) aimed to develop a dielectric-elastomer and micro-electronics-based skin-like sensing solution for the structural monitoring of transport infrastructure that will offer spatial sensing of reversible strains. The technology was targeted at requiring little power to operate, being easy to install and being low cost compared to existing sensors. This self-monitoring and self-reporting system was to be implemented in the case of bridges, and test, refine, evaluate and benchmark the monitoring system.
- INFRALERT (2015-2018) aimed to develop an expert-based information system to support and automate linear asset infrastructure management from measurement to maintenance. This includes the collection, storage and analysis of inspection data, the deduction of interventions to keep the performance of the network in optimal condition, and the optimal planning of maintenance interventions. The project also assessed new construction strategic decisions. The objectives were to develop and deploy solutions to ensure the operability of infrastructure under traffic disruptions and ensuring service reliability and safety by minimising incidences and failures.
- For rail infrastructure, DESTination Rail (2015-2018) was aimed at developing management tools based on scientific principles for risk assessment using real performance measurements and other data stored in an information management system. This project was specifically aimed at managing European rail infrastructure. The objectives of the project included preventing unnecessary line restrictions and closures using monitoring and real-time analysis and reducing maintenance costs by optimising interventions in the life-cycle of the asset.
- ECOROADS (2015-2017) aimed to overcome, where appropriate, the barrier established by a formal interpretation of the two Directives 2008/96/EC (on road infrastructure safety management) and 2004/54/EC (on tunnels), that in practice do not foresee the same road safety audits/inspections to be performed on open roads and in tunnels. To overcome this legal barrier, the project examined a common-coordinated enhanced approach by applying some of the concepts of the Directive 2008/96/EC to transition areas between tunnels and open roads, without jeopardising (but rather complementing) the usual tunnel safety management operations.

8.4.3 Achievements

Several projects have improved on current-state-of-the-art in the research area of life-cycle optimisation of assets of European infrastructure. The results and achievements of these projects are presented below.

The COBRI project has developed a simple and efficient system that is also low-cost and portable. The main technological innovation is a new product capable of acquiring ultrasound data in real time from concrete structures and presenting this data in a 3D video format. The project developed and tested the technology in the field, which leads to a significant achievement in terms of non-destructive testing/evaluation.

A track monitoring system for condition-based track maintenance has been delivered by the WARNTRACK project. Early commercial success of the product has been achieved, with several commercial contracts either in operation or being shipped. At the time of completion of the project (2017), two patents had been filed; these are expected to lead to further projects and exploitation. Four commercial contracts have been delivered and are running, with many more customers engaged in advanced negotiations. This project has achieved significant progress for track condition monitoring, being implemented on a wide scale.

The results of SmartSite were presented in a final demonstrator. This showed achievements in terms of several subsystems using artificial intelligence and software solutions for processes in road construction. Advantages over the current state of construction practice included significantly less logistical downtime, improvements in the just-in-time arrival of materials and comprehensive improvements of the site communication. Overall, the use of SmartSystem showed a fundamental improvement, streamlining and automation of the construction processes as well as their monitoring and documentation.

SENSKIN implemented an infrastructure monitoring technology on actual bridges. In total, 24 SENSKIN sensors were installed at six locations of interest on the steel superstructure, concrete piers and the concrete deck of the bridge. Also installed were conventional sensors to compare the results. The solution provided much easier and faster installation compared to conventional strain gauges, as well as wireless capabilities. However, the technology showed that it was susceptible to temperature variations and noise in the output and slow transfer of data.

The INFRALERT project piloted the sensor monitoring system on both rail and road infrastructure, with a pilot in Portugal demonstrating the road capabilities and a demonstrator in Sweden assessing the rail capabilities. These pilot tests were scheduled to conclude in May 2018, and the results from these two pilot tests will demonstrate the multimodal capabilities of the infrastructure monitoring system.

Further demonstration of rail infrastructure monitoring technologies was shown in DESTination RAIL. In this project, two demonstration projects were undertaken to show the effectiveness of the holistic management tool based on the FACT (find, analyse, classify and treat) principle. The first demonstration project involved installation of a full vibration monitoring system and structural health monitoring system for a viaduct. Data was gathered over four months and novel techniques were employed to utilise this data for modelling, assessment of dynamic allowance and incorporation into probabilistic assessment of the structure. In the second demonstration project, a length of railway embankment was rehabilitated with minimal disruption to the traffic.

ECOROADS focused on joint safety operations for roads and tunnels, and the project found that, when managing real traffic flows in real infrastructure, there is a need for coordinated actions. Five test sites were used for the joint safety operations. These five tests had high efforts and resources spent on them, due to the experimental phase of the project. However, the results from these tests and particularly the procedures and guidelines are now validated and made public. Therefore, these guidelines can now be used by future infrastructure managers.

8.4.4 Implications for future research

There are many projects researching how to monitor structures to better plan maintenance which can lead to better utilisation of the infrastructure. SENSKIN pilot tested an infrastructure monitoring technology at several locations on a bridge structure. The results which came out of this research found that the technology was susceptible to temperature and noise variations, and sometimes the transfer of data was slow. To fully commercialise this product, further research is needed to address these issues an investigate possible mitigations to the problems.

There were multiple projects which had monitoring technologies at the demonstrator development phase. DESTination RAIL demonstrated rail infrastructure monitoring technologies, and the project SmartSite presented a final demonstrator relating to using artificial intelligence and software solutions for road construction. Despite these two projects offering different technologies, they show that the area of research of life-cycle optimisation of assets is far along the development phase. Research is now needed into the commercial aspects of these projects to help with the business plans and bring the products to market.

The measurement of carbon emissions during the construction, maintenance and eventual deconstruction or recycling of infrastructure has not received much research attention. While whole life-cycle costs are usually considered, it is not often that life-cycle carbon emissions are considered. Research should be conducted into the life-cycle carbon emissions from transport infrastructure, which would help inform passengers and freight operators over the carbon impact of their transportation.

8.4.5 Implications for future policy development

The use of software and data platforms in the field of life-cycle optimisation of assets is clearly an important upcoming area of research. Within this topic, the project SENSKIN found that the transfer of data was often slow. SmartSite is also investigated the use of software solutions for road construction. In terms of non-destructive testing, the project COBRI developed a new product to gather and present ultrasound data in a 3D video format. There is a need to address the issues around data storage and transfer; as with the increasing amount of data, high-quality secure digital infrastructure is required to ensure the efficient and safe operation of the digital systems. European policy could be provided to promote the secure storage and transfer of data within transport infrastructure.

The project ECOROADS found that managing traffic flows in infrastructure, particularly when considering roads and tunnels, there is a real need for coordination between various parties. Five tests were conducted, and the guidelines developed are now available to infrastructure managers. Policy could be in place to ensure that this joint-operation of safety knowledge and guidelines is widely available, and the use of this research encouraged.

There is not much research into the decarbonisation over the life-cycle of transport infrastructure, which does not offer support towards the transport decarbonisation targets. Future European policy could focus on improving the decarbonisation aspects of the life-cycle optimisation of assets to further reduce the carbon emissions from the transport sector.

8.5 Sub-theme 5 – Operation, efficiency and resilience

Most transport infrastructure is closely operated to manage capacity, performance and safety of users. Operational activities include mitigating the impacts of severe weather, control movement of traffic and reactive responses to incidents that may prevent operation. The focus of operations is to achieve the maximum capacity or throughput for the transport infrastructure.

When the operation of infrastructure is affected by disruption, energy consumption and carbon emissions can increase due to inefficient operation of delayed traffic. Therefore, there is required optimisation between quality of system performance, cost and carbon impact of additional infrastructure, and the cost and carbon impact of disrupted operations.

8.5.1 Overall direction of R&I

Operation, efficiency and resilience of transport infrastructure covers a wide variety of research topics. An important area of research is the operation of freight containers, and the optimisation of port and inland freight cargo loading and unloading. This has received particular attention and will help to improve the efficiency of the system as well as reducing congestion around the terminals.

On the operation of infrastructure, there are projects researching effective maintenance techniques to reduce the unforeseen maintenance and therefore increase the efficiency and resilience of the transport infrastructure. These projects have a specific research area and are typically focused on one transport mode.

8.5.2 R&I activities

A selection of projects that have shown good examples of innovation in the operation, efficiency and resilience of European infrastructure are shown below. These projects have been chosen as they have either been completed recently, show well-reported results and have a high project value.

- DuaLine (2015-2017) aimed at bringing road marking retro reflectance measuring equipment to the global market. The DuaLine project has the objective to complete the development of this technology from TRL 7 to TRL 9, for full commercial application and technology available for customers. The technology allows for inspection of road lines at both sides of a road lane, therefore saving 50 % of line inspection cost and providing a much safer night-time driving environment.
- SafeTrain (2015-2017) aimed at piloting and industrial validation of autonomous and sustainable animal deterring for rail transport. Animals living within the vicinity of rail lines quickly acclimatise to the sound of trains, and therefore begin to ignore the danger of them when crossing railway lines. The device researched in this project emits a series of sounds which alerts and deters animals from the railway lines. The goal of the SafeTrain project was to pilot and test in real environment the autonomous UOZ-2 animal deterring system that will be integrated with the automatic train detection system.
- IN2RAIL (2015-2018) aimed at making advances towards achieving the global shift to rail objectives of capacity, reliability and life-cycle costing. IN2RAIL contained three core sub-projects that linked together infrastructure re-design and associated asset maintenance, with rail traffic control and traction energy management. This was a large and complex project, which placed specific emphasis on creating governance processes, analytical methodologies and technical frameworks that both stimulated innovation and aided integrated system designs.
- WRIST (2015-2018) had an overall objective to deliver a step-change in the joint performance and reliability for rails, therefore resulting in an extended in-service life. An aim was to significantly reduce the cost for maintenance of track whilst also freeing up more capacity for rail traffic, including less unforeseen maintenance. To do this, the project targeted the development of two flexible and cost-effective joining processes for rails, which also recognise the move of the industry towards higher speeds and axle loads and the needs to increase capacity.
- There are projects researching the optimisation of port and inland terminals in terms of freight loading and unloading, as well as freight cargo transportation. RCMS (2015-2017) is a robotic parking system that can efficiently manage and handle more containers per square-metre than traditional handling systems used in port and inland terminals. This new system also provides optimal and adaptable responses to the needs of shipping companies and port terminal operators, as well as to truck and railway operators. The goal of this project was to develop a detailed simulation model for RCMS to be evaluated in two terminals and compared to other state-of-the-art container handling technologies. SAFE-CTS (2015-2017) focused on a truck/train container transfer system (CTS) and a disruptive re-organisation of the freight logistical networks. The overall objective was to optimise the inland freight value chain through cheaper, faster and greener transportation of goods. The project aimed to demonstrate the SAFE-CTS technology on a pilot point-to-point route, transporting cargo between two European ports. The objective for this project was to showcase the concept and validate the technology under operational conditions.
- The overall objective of Runway-Star (2017-2019) was to build and demonstrate a full-scale aircraft washing/de-icing facility that will be a green, predictable, fast, safe and cost-effective way to wash and de-ice aircraft and improve airport efficiency. The project aims at minimising the disruption that can be associated with flight handling, and therefore provide time savings through the efficiency of the system.
- AEROBI (2015-2018) aimed at developing a robotic system to inspect bridges and assess their status. The project is based on the development of an aerial unmanned system equipped with sensors that can detect, identify and measure anomalies and defects. The goal was to create a system which performs as automatically as possible to inspect the bridge and analyse the structural health. The scope of this project included technical, operational and commercial aspects of the monitoring system.
- ZAPINAMO (2017-2018) is an easily deployable, stored energy based EV rapid charging system. The technology works in the same way as a power bank for a mobile phone, but it is larger and provides faster charging. Within the ZAPINAMO project, the project partners focused on two initial market opportunities: the Zapstore, an EV fast-charging point without the need for expensive infrastructure modifications; and the ZuPa, a mobile charge-delivery vehicle. The objectives of the project were to identify areas and stakeholders that the EV charging infrastructure would be most beneficial to, and then to produce a detailed business plan for the selected areas.

8.5.3 Achievements

Several projects have improved on current-state-of-the-art in the research area of operation, efficiency and resilience of European infrastructure. The results and achievements of these projects are presented below.

Results from the project DuaLine showed successful completion of products for the European market and the American market. Both products have been subjected to rigorous testing and have been independently tested and certified by leaders in the retro-reflection measurement industry. The project has helped to successfully sell two systems in Europe. Road maintenance companies can now purchase these products; therefore, the project has raised the technology from TRL 7 to TRL 9.

Within the IN2RAIL project an aim was to create governance processes, analytical methodologies and technical frameworks that both stimulated innovation and aided integrated system designs. These processes have been successfully implemented which is evident by the technical progress achieved within the various work packages. The project had a total of 67 deliverables, so represents a significant amount of research into the rail infrastructure sector. Each of the work packages within this project have been developed with respect to the technical progress beyond the current state-of-the-art. Progress has been made in the field of smart infrastructure, intelligent mobility management and power supply and energy management.

A number of technologies have been researched during the WRIST project for rail infrastructure. The first work-package developed a methodology for welding which would protect against rail surface damage. Design and development of an automated aligning, forging and shearing unit has been carried out in the second work-package. This resulted in a product prototype. The major result of this project transformed a concept in orbital friction welding into a large-scale industrial machine, and one of the largest in Europe. This welding process allows for long or large components (for example railway tracks) to be welded together easily and efficiently. Due to this process, the welds require less unforeseen maintenance; which increases the rail network capacity and improves the resilience of the infrastructure.

The results from the two case studies of the RCMS project showed an advantage of the container handling technology over current state-of-the-art. Significant progress has been achieved also in terms of system and sub-system design. Documents for the design of the systems and sub-systems have been presented, explaining the assumptions and decision taken in the process and sets the base for further development.

SAFE-CTS designed and manufactured test units of a container transfer system aiming to improve the inland freight value chain. After the manufacturing and installation of the units, they were intensively tested both statically and dynamically (loaded up to 30 tonnes) between a truck trailer and a train wagon. These tests were run in a warehouse environment, enabling a controlled testing environment and an intensive programme of tests. This research has led the way for a future live railway pilot, and assessment of possible business models for the technology.

During the Runway-Star project, the overall aircraft de-icing/washing system functional requirements were developed, based on specifications from the largest ground handler in Scandinavia and input received from the aviation network. The de-icing/washing hangar has been designed and is currently being built. Assembly of the test jig was also completed, and mechanical parts were tested and further optimised. The project has also purchased a test aircraft which will be used to test the mechanical and functional capabilities of the hangar.

In the AEROBI project, the first version of the computer vision module to inspect the structural health of bridges was tested on a real bridge in Spain in December 2016. The results showed satisfactory images and identification of cracks in the bridge structure. The project has reached a large public, end-user, stakeholder and expert audience, and the results show a promising business case for the technology.

8.5.4 Implications for future research

The project Runway-Star has so far designed a de-icing/washing hangar for aircraft and has just purchased a test aircraft to assess the mechanical and functional capabilities of this hangar. Further research to validate and pilot test this technology is definitely needed, as it has the potential to improve airport efficiency which is vital for the anticipated rise in air transport in Europe.

Reducing carbon emissions from operations is first achieved by making the operation as efficient as possible. In managed systems such as ports, airports and railways the scheduling of movements means that maximum productivity can be reached for a given amount of infrastructure before investment in additional infrastructure is required. This method minimises the amount of carbon emissions from construction and maintenance of the infrastructure, as less is needed for a given volume of traffic. The projects RCMS and

SAFE-CTS have both researched innovative container handling systems to improve the operational efficiency at freight terminals. The downside to this approach is that there may be no additional capacity to meet peak demand or accommodate disrupted traffic flows. Research would be useful to explore the carbon trade-offs between investing carbon in excess infrastructure capacity, and the carbon used by traffic movements delayed by congestion or disruption while the infrastructure operates at full capacity.

There have been large projects researching multiple aspects of improved railway operational efficiency, specifically IN2RAIL which had a total of 67 deliverables. The research to date has generally been high level, assessing the different options available for improving rail infrastructure. Further benefits would be provided by developing specific technologies around digital train control systems. There could be a substantial increase in the capacity of rail lines throughout Europe by using smart control systems.

8.5.5 Implications for future policy development

The results from the projects (RCMS and SAFE-CTS) researching optimal cargo loading and unloading at port and inland terminals showed positive results. Efficiency and reduced congestion are the main benefits of these operation systems. Reducing congestion at ports and terminals will improve the air quality around these areas, in line with current European policy. It could be helpful for local authorities to raise the awareness of these systems and encourage operators to use them in order to reduce the congestions around freight terminals, and therefore improve the air quality around the terminals.

Rail transport, both for passenger and freight, has the ability to offer much lower emissions than road transport[41,42]. Therefore, by improving the operational efficiency of rail transport it could create additional capacity on the network. Additional capacity would increase the amount of passenger and freight rail traffic and subsequently reduce road congestion. Improving the rail freight capacity on the network in conjunction with the improved operational efficiency at ports and terminals would significantly aid shifting road freight to rail freight. This is something that should be considered in any new freight transport policy.

Therefore, the research into the operational efficiency of rail transport could aid the decarbonisation of the transport sector if positive results arise from future rail infrastructure projects. Incentives could be proposed to encourage modal shift from road to rail, which would help achieve decarbonisation targets.

[41] CarbonCaron dioxide emissions from passenger transport; European Environment Agency; 2016

[42] Rail Emission Model; AEA Technology Environment, 2001

9 Conclusions

Focusing on selected EU funded projects starting from 2012 onwards, this report presents a comprehensive analysis of R&I in transport infrastructure in Europe in the last years. The report identifies relevant researched technologies and their development phase and highlights the relevant policy context and the market activities both in Europe and outside. From the assessment carried out, key conclusions are:

- Over € 1 061 million has been invested in transport infrastructure research projects through European research framework programmes since 2007. This includes € 701 million of EU funding and € 360 million of own contributions by beneficiary organisations. This amount is likely to grow as several funding calls are yet to be launched.
- Spending on INF research under the H2020 framework programme peaked in the beginning of 2018. Road, rail and multimodal transport receive the greatest interest, while waterborne transport receives the smallest amount of funds for INF research amongst all modes.
- From a text analysis on scientific research in the Scopus database, “maintenance” and “technological changes” keywords increased significantly in the last two years. Likewise, research on “construction” seems to have increased in 2018 compared to 2017.
- Similar technologies are researched in FP programmes at different development phases. Technologies for rail noise and vibration reduction are researched at a low development phase in FPs. Structural vibration heath monitoring based on modelling, information systems for infrastructure management and road infrastructure management system testing technologies, are researched both at low and at high development phases, including implementation. Considering these findings, an effort to reduce duplication of research should be made.
- There has been significant funding awarded to projects dealing with crisis management; including developing a standardisation of security of infrastructure and tools to provide advice in the event of a crisis.
- Limited research has been done into the effects of using unconventional transport systems for freight.
- Many projects research how to monitor structures to better plan maintenance, which can lead to better utilisation of the infrastructure.
- The measurement of carbon emissions during the construction, maintenance and eventual deconstruction or recycling of infrastructure has not received much research attention.
- There have been large projects researching multiple aspects of improved railway operational efficiency.
- Research project outcomes are well documented in Europe; however, these outcomes are not always accessible to stakeholders or they may not be aware of them.

The analyses performed in this report are subject to some limitations, namely:

- The TRIMIS projects and programmes database has only recently been consolidated, yet there are some issues that could be addressed better in the future, in particular for what regards the projects’ STRIA roadmap tagging.
- The technology identification and the corresponding development phase assessment (Chapter 6) is still on-going, and the technology taxonomy hasn’t reached yet a full maturity.
- The methodology behind the text analysis on transport infrastructure academic research (Chapter 7) is still under development. It is expected that in future reports, the analyses will be more thorough.

Altogether, this report provides a comprehensive and up-to-date review of transport infrastructure R&I across Europe. The findings and the insights into the current R&I status and future needs, help the STRIA WG to better identify R&I activities and provides valuable information to transport infrastructure stakeholders.

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List of abbreviations and definitions

AASHTO American Association of State Highway and Transportation Officials

ALT Alternative Energy

ASCE American Society of Civil Engineers

AT Austria

BCR Benefit-Cost Ratio

BE Belgium

BG Bulgaria

CAT Connected & Automated Transport

CCAM Cooperative connected and automated mobility

CEF Connecting Europe Facility

C-ITS Cooperative Intelligent Transport Systems

CO_2 Carbon dioxide

CORDIS Community Research and Development Information Service

COST Co-Operations in Science and Technology

CRP Cooperative Research Programme

CTS Container transfer system

CY Cyprus

CZ Czech Republic

DE Germany

DG MOVE Directorate-General for Mobility and Transport

DG RTD Directorate-General for Research and Innovation

DK Denmark

DOT Department of Transportation

DSRC Dedicated short-range communication

EC European Commission

EE Estonia

EETS European Electronic Toll Service

ETS Emission Trading System

EIB European Investment Bank

EL Greece

ELT Electrification

ERTMS European Rail Traffic Management System

ES Spain

ETS Emissions Trading System

EU European Union

EU-13 Group of 13 EU countries: Bulgaria (BG), Czech Republic (CZ), Croatia (HR), Cyprus (CY), Estonia (EE), Hungary (HU), Latvia (LV), Lithuania (LT), Malta (MT), Poland (PL), Romania (RO), Slovakia (SK) and Slovenia (SI)

FAA Federal Aviation Administration

FHA	Federal Highway Administration
FI	Finland
FP	Framework Programme
FP7	7th Framework Programme
FR	France
FRA	Federal Railroad Administration
FRFCU	Fundamental Research Funds for the Central Universities
FRP	Fibre reinforced polymer
GDP	Gross Domestic Product
GPS	Global Positioning System
H2020	Horizon 2020 Framework Programme
HGV	Heavy goods vehicles
HR	Croatia
HU	Hungary
IE	Ireland
INF	Infrastructure
IoT	Internet of Thing
iSHM	indirect Structural Health Monitoring
IT	Italy
ITF	International Transport Forum
ITS	Intelligent Transport Systems
IWW	Inland waterways
JRC	Joint Research Centre
LT	Lithuania
LU	Luxembourg
LV	Latvia
MaaS	Mobility-as-a-Service
MOT	Ministry of Transport
MS	Member States
MT	Malta
NASA	National Aeronautics and Space Administration
NBRPC	National Basic Research Program of China
NETT	New and emerging technologies and trends
NL	Netherlands
NPF	National Policy Framework
NSFC	Natural Science Foundation of China
NTM	Network & Traffic Management
OECD	Organisation for Economic Co-operation and Development
PL	Poland

PPP	Public Private Partnerships
PT	Portugal
RD&T	Research Development and Test
REGEX	Regular expressions
R&I	Research and innovation
RO	Romania
SE	Sweden
SESAR	Single European Sky ATM Research
SHM	Structural health monitoring
SI	Slovenia
SK	Slovakia
SME	Small Medium Enterprise
SMO	Smart Mobility
STRIA	Strategic Transport Research and Innovation Agenda
TEN	Trans-European network
TEN-T	Trans-European transport network
TFL	Transport for London
TIRI	Transport Infrastructure Resilience Indicator
TPRI	Transport Planning and Research Institute
TRB	Transportation Research Board
TRID	Transport Research International Documentation
TRIMIS	Transport Research and Innovation Monitoring and Information System
TRL	Technology readiness level
TTI	Transport and Telecommunication Institute
UK	United Kingdom
US	United States
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
VDM	Vehicle Design & Manufacturing
WG	Working Group

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Annexes

Annex 1: Project table

The following table shows all projects that were considered during the development of this report and the sub-theme(s) under which they were considered.

Project acronym	Project name	Project duration	Source of funding	Governance	Pricing	Intermodality	Life-cycle	Operation
4SBLOCK	Pavement Building System based on Detachable and Embedded Blocks	2016-2017	H2020-EU.3.4		Y			
AEROBI	AErial RObotic System for In-Depth Bridge Inspection by Contact	2015-2018	H2020-EU.2.1					Y
A-FOD	SAFER and TIMELY FLIGHTS with Automated Foreign Object Detection System	2017-2018	H2020-EU.3.4					Y
ALLIANCE	Enhancing Excellence and Innovation Capacity in Sustainable Transport Interchanges (ALLIANCE)	2016-2018	H2020-EU.4.	Y				
AM4INFRA	Common Framework for a European Life Cycle based Asset Management Approach for transport infrastructure networks	2016-2018	H2020-EU.3.4		Y			
Andromeda	Predictive Maintenance for railway switches. Smart sensor networks on a machine learning analytics platform	2017-2019	H2020-EU.3.4					Y
ATARD	Air Transport and Regional Development	2015-2019	COST	Y	Y			
ATENA	Advanced Tools to assEss and mitigate the criticality of ICT compoNents and their dependencies over Critical InfrAstructures	2016-2019	H2020-EU.3.7			Y		Y
AUTOC-ITS	Regulation Study for Interoperability in the Adoption of Autonomous Driving in European Urban Nodes	2016-2018	CEF - Connecting Europe Facility			Y		
BENEFIT	Business Models for Enhancing Funding and Enabling Financing of Infrastructure in Transport	2014-2016	H2020-EU.3.4		Y			

Project acronym	Project name	Project duration	Source of funding	Governance	Pricing	Intermodality	Life-cycle	Operation
BRIDGE SMS	Intelligent Bridge Assessment Maintenance and Management System	2015-2018	FP7-PEOPLE	Y				
CAPACITY4RAIL	Increasing Capacity 4 Rail networks through enhanced infrastructure and optimised operations	2013-2017	FP7-TRANSPORT					Y
C-BORD	effective Container inspection at BORDer control points	2015-2018	H2020-EU.3.7					Y
CIPSEC	Enhancing Critical Infrastructure Protection with innovative SECurity framework	2016-2019	H2020-EU.3.7		Y			Y
CITADEL	Critical Infrastructure Protection using Adaptive MILS	2016-2019	H2020-EU.3.7	Y				
COBRI	Ultrasound NDE tomograph. Design and construction of a portable 3D ultrasound scanner for non-destructive testing and evaluation (NDT and NDE) of concrete in bridges and other building structures	2015-2017	H2020-EU.3.4				Y	
CYRail	Cybersecurity in the RAILway sector	2016-2018	H2020-EU.3.4			Y		Y
DATASET2050	Data driven approach for a Seamless Efficient European Travelling in 2050	2014-2017	H2020-EU.3.4			Y		
DESTINATE	Decision supporting tools for implementation of cost-efficient railway noise abatement measures	2016-2018	H2020-EU.3.4		Y		Y	
DESTinationRAIL	Decision Support Tool for Rail Infrastructure Managers	2015-2018	H2020-EU.3.4				Y	
DIGITALIA 2	Disruptive process for the construction of railway transition zones, reducing drastically construction and maintenance costs	2017-2019	H2020-EU.3.4				Y	
DuaLine	The validation, certification and industrial testing of advanced road marking retro reflectance (RL) measuring equipment (RetroTek-M) for the global market	2015-2017	H2020-EU.3.4					Y

Project acronym	Project name	Project duration	Source of funding	Governance	Pricing	Intermodality	Life-cycle	Operation
DURABROADS	Cost-effective DURABle ROADS by green optimised construction and maintenance	2013-2017	FP7-TRANSPORT					Y
ECOLUP	Smart collect points as an innovative logistic solution to shorten fruit and vegetables supply chain	2017-2017	H2020-EU.3.4	Y				
ECOROADS	Effective and COordinated ROAD infrastructure Safety operations	2015-2017	H2020-EU.3.4				Y	Y
ECOSSIAN	European Control System Security Incident Analysis Network	2014-2017	FP7-SECURITY			Y		
EnergyKeeper	Keep the Energy at the right place!	2017-2019	H2020-EU.3.3	Y	Y	Y		
ENVISION	Enhanced Situational Awareness through Video Integration with ADS-B Surveillance Infrastructure on Airports	2018-2019	H2020-EU.3.4					Y
Fair Stations	Future Secure and Accessible Rail Stations	2017-2019	H2020-EU.3.4			Y		Y
FASTSCALE	Fast-Beam - Novel modular repair and newbuilding system for concrete bridges	2016-2017	H2020-EU.3.4		Y		Y	
FFL4E	Future Freight Loco for Europe	2016-2019	H2020-EU.3.4					Y
FOX	Forever Open infrastructure across (X) all transport modes	2015-2017	H2020-EU.3.4			Y		
FR8RAIL	Development of Functional Requirements for Sustainable and Attractive European Rail Freight	2016-2019	H2020-EU.3.4		Y		Y	Y
FREVUE	FREVUE VALIDATING FREIGHT ELECTRIC VEHICLES IN URBAN EUROPE	2013-2017	FP7-TRANSPORT	Y	Y			
GoSAFE RAIL	Global Safety Management Framework for RAIL Operations	2016-2019	H2020-EU.3.4				Y	
GRAILS-SWE	Greater RAIL Safety using the Smart Washer Ecosystem	2017-2017	H2020-EU.3.4				Y	Y

Project acronym	Project name	Project duration	Source of funding	Governance	Pricing	Intermodality	Life-cycle	Operation
Greenrail	Greenrail, innovative and sustainable railway sleepers: the greener solution for railway sector	2016-2018	H2020-EU.3.4					Y
HPCForEVs	High Power Charger For Electric Vehicles	2017-2019	H2020-EU.3.4		Y			Y
HYBRID-INFRA-RAIL	Deployment of hybrid systems for rail infrastructure to reduce energy consumption by 30 %	2016-2019	CEF Transport		Y		Y	Y
IBiS	Full scale demonstration of an Innovative solution for Baggage Handling Systems at airports (IBiS)	2017-2017	H2020-EU.3.4					Y
IMPROVER	Improved risk evaluation and implementation of resilience concepts to critical infrastructure	2015-2018	H2020-EU.3.7	Y				Y
IN2DREAMS	IN2DREAMS (INtelligent solutions 2ward the Development of Railway Energy and Asset Management Systems in Europe)	2017-2019	H2020-EU.3.4				Y	Y
IN2RAIL	Innovative Intelligent Rail	2015-2018	H2020-EU.3.4			Y		Y
IN2SMART	Intelligent Innovative Smart Maintenance of Assets by integRated Technologies	2016-2018	H2020-EU.3.4					Y
In2Track	Research into enhanced tracks, switches and structures	2016-2019	H2020-EU.3.4				Y	Y
INFRALERT	Linear Infrastructure Efficiency Improvement by Automated Learning and Optimised Predictive Maintenance Techniques	2015-2018	H2020-EU.3.4				Y	
INFRAVATION	ERA-NET Plus on Infrastructure Innovation	2014-2018	FP7-TRANSPORT	Y	Y			
IntelHeat	Intelligent control system for railway points heating with supreme saving of electicity	2017-2018	H2020-EU.3.4					Y

Project acronym	Project name	Project duration	Source of funding	Governance	Pricing	Intermodality	Life-cycle	Operation
INTERMODEL EU	Simulation using Building Information Modeling Methodology of Multimodal, Multipurpose and Multiproduct Freight Railway Terminals Infrastructures	2016-2019	H2020-EU.3.4			Y		
lif-E-Buoy	Compact hydro generator for electric vehicles charging stations (to serve as an energy lifebuoy)	2018-2018	H2020-EU.2.1		Y	Y		
LNG Blue Corridors	LNG Blue Corridors	2013-2017	FP7-SST	Y				
MASS	Micro AIS Shore Station - MASS	2017-2017	H2020-EU.3.4					Y
MESMERISE	Multi-Energy High Resolution Modular Scan System for Internal and External Concealed Commodities	2016-2019	H2020-EU.3.7					Y
MOMIT	Multi-scale observation and monitoring of railway infrastructure threats	2017-2019	H2020-EU.3.4					Y
NeTIRail-INFRA	Needs Tailored Interoperable Railway	2015-2018	H2020-EU.3.4			Y		
OPEUS	Modelling and strategies for the assessment and OPtimisation of Energy USage aspects of rail innovation	2016-2019	H2020-EU.3.4	Y			Y	
PACS	Pantograph Active Control System for e-Highways	2017-2017	H2020-EU.3.4				Y	
PANDHUB	Prevention and Management of High Threat Pathogen Incidents in Transport Hubs	2014-2017	FP7-SECURITY	Y				
PINTA	IP1 Traction TD1 and Brakes TD5 - Phase 1	2016-2018	H2020-EU.3.4				Y	
PJ02 EARTH	Increased Runway and Airport Throughput	2016-2019	H2020-EU.3.4	Y				
POWERVE	Portable Weigher for Railway Vehicles	2016-2017	H2020-EU.3.4				Y	
PROTECT	Pervasive and UseR Focused BiomeTrics BordEr ProjeCT	2016-2019	H2020-EU.3.7			Y		

Project acronym	Project name	Project duration	Source of funding	Governance	Pricing	Intermodality	Life-cycle	Operation
RADARR	INNOVATIVE TECHNOLOGY FOR RAPID AND DURABLE ASPHALT ROAD REPAIRS	2017-2017	H2020-EU.3.4		Y		Y	
RAGTIME	Risk based approaches for Asset inteGrity multimodal Transport Infrastructure ManagEment	2016-2019	H2020-EU.3.4	Y	Y			
Railscope	Improving Railway Safety Through Innovative Sensor System	2017-2018	H2020-EU.3.4					Y
RCMS	Rethinking Container Management Systems	2015-2017	H2020-EU.3.4					Y
REFINET	REthinking Future Infrastructure NETworks	2015-2017	H2020-EU.3.4	Y				
RESILENS	RESILENS: Realising European ReSiliencE for CritIcaL INfraStructure	2015-2018	H2020-EU.3.7					Y
RESOLUTE	RESilience management guidelines and Operationalization appLied to Urban Transport Environment	2015-2018	H2020-EU.3.7					Y
Runway-Star	A Novel Solution for Aircraft Washing and De-Icing	2017-2019	H2020-EU.3.4					Y
SAFE4RAIL	SAFE architecture for Robust distributed Application Integration in roLling stock	2016-2018	H2020-EU.3.4				Y	
SAFE-CTS	Efficient and cost-effective intermodal road-rail container freight system	2015-2017	H2020-EU.3.4					Y
SafeTrain	Piloting and industrial validation of autonomous and sustainable animal deterring system for the rail transport	2015-2017	H2020-EU.3.4					Y
SAFTInspect	Ultrasonic inspection solution for railway crossing points	2017-2019	H2020-EU.3.4				Y	Y
S-CODE	Switch and Crossing Optimal Design and Evaluation	2016-2019	H2020-EU.3.4					Y
SCOUT	Safe and COnnected aUtomation in road Transport	2016-2018	H2020-EU.3.4	Y	Y			

Project acronym	Project name	Project duration	Source of funding	Governance	Pricing	Intermodality	Life-cycle	Operation
SENSKIN	SENsing SKIN' for Monitoring-Based Maintenance of the Transport Infrastructure (SENSKIN)	2015-2018	H2020-EU.3.4				Y	Y
Skylynx	Upgrading Railways from the Air	2017-2017	H2020-EU.3.4				Y	
SmartResilience	Smart Resilience Indicators for Smart Critical Infrastructures	2016-2019	H2020-EU.3.7					Y
SmartSite	Optimisation, demonstration and implementation of an all-encompassing smart site management system for infrastructure construction and maintenance	2015-2017	H2020-EU.3.4				Y	
SMARTV2G	Smart Vehicle to Grid Interface	2011-2014	FP7-ICT	Y				
SocialCar	SocialCar	2015-2018	H2020-EU.3.4	Y	Y	Y		
SPA4ROADS	Sustainable polymers application for preventive maintenance and upgrading of resilient and secureroads	2016-2017	H2020-EU.3.4				Y	Y
SPEED-EU	Damping device to solve the pantograph-line capture problems, especially for the EU high-speed railways lines	2018-2018	H2020-EU.3.4					Y
SSBUMP	SMART SPEED BUMP	2017-2017	H2020-EU.3.4					Y
SUNJET II	SUstainable Network for Japan-Europe aerospace research and Technology cooperation II	2014-2017	H2020-EU.3.4	Y				
SURVEIRON	SURVEIRON: Advanced surveillance system for the protection of urban soft targets and urban critical infrastructures	2016-2018	H2020-EU.3.7	Y				Y
tCat	Disrupting the rail maintenance sector thanks to the most cost-efficient solution to auscultate railways overhead lines reducing costs up to 80 %	2017-2019	H2020-EU.3.4		Y		Y	

Project acronym	Project name	Project duration	Source of funding	Governance	Pricing	Intermodality	Life-cycle	Operation
TEST-inn	TEST-INNOVATIVE LOAD APPLICATION MONITORING SYSTEMS	2018-2019	H2020-EU.3.4				Y	
TEST-inn	TEST-INNOVATIVE LOAD APPLICATION MONITORING SYSTEMS	2018-2019	H2020-EU.3.4					Y
TownHall24	A 24/7 platform providing access to services for isolated communities and reduced mobility residents	2017-2017	H2020-EU.3.4	Y				
TRAINSFARE	SMART TOOL TO PROTECT PUBLIC TRANSPORT REVENUES, ASSETS, PASSENGERS AND MOBILITY	2017-2019	H2020-EU.3.4		Y			
USE-IT	Users, Safety, security and Energy In Transport Infrastructure	2015-2017	H2020-EU.3.4			Y		
VERT	Vertex switch - the foundation for a more sustainable and reliable railway transport system	2017-2017	H2020-EU.3.4					Y
VITE	Virtualisation of the testing environment	2016-2018	H2020-EU.3.4				Y	
WARNTRAK	Rail track monitoring system - Wireless Autonomous On-Board System measuring vibration with continuous reporting to reduce maintenance costs and enhance reliability and safety	2015-2017	H2020-EU.3.4				Y	Y
WRIST	Innovative Welding Processes for New Rail Infrastructures	2015-2018	H2020-EU.3.4					Y
XP-DITE	Accelerated Checkpoint Design Integration Test and Evaluation	2012-2017	FP7-SECURITY	Y				
ZAPINAMO	ZAPINAMO - Affordable, future-proof rapid charging infrastructure for electric vehicles from stored (clean and economical) energy	2017-2018	H2020-EU.3.4					Y

Annex 2a: Regular expression analysis keywords – FP research

REGEX KEYWORDS:

```
# Topic 1 = "Pricing and Charging"
key_1 <- c("pric*|charg*|toll*")
# Topic 2 = "Financing"
key_2 <- c("financ*")
# Topic 3 = "Multimodality, interoperability and interconnectivity"
key_3 <- c("multimodal*|interoperab*|interconnect*")
# Topic 4 = "Logistics"
key_4 <- c("logistic*")
# Topic 5 = "Construction"
key_5 <- c("construct*")
# Topic 6 = "Maintenance"
key_6 <- c("maintenance")
# Topic 7 = "Environmental concerns"
key_7 <- c("environment*")
# Topic 8 = "Safety and security"
key_8 <- c("safe*|secur*")
# Topic 9 = "User needs"
key_9 <- c("user*")
# Topic 10 = "Resilience"
key_10 <- c("resilien*")
# Topic 11 = "Technological changes in transport"
key_11 <- c("technolog*")
# Topic 12 = "Communication and data transfer"
key_12 <- c("communicat*")
```

Annex 2b: Regular expression analysis keywords – Scopus research

REGEX KEYWORDS:

Baseline

TITLE-ABS ("transport infrastructure" OR "transportation infrastructure") AND PUBYEAR > 2003 AND (LIMIT-TO (SRCTYPE,"j"))

Topic 1 "Pricing and charging"

TITLE-ABS ("transport infrastructure" OR "transportation infrastructure") AND PUBYEAR > 2003 AND TITLE-ABS (charg*) OR TITLE-ABS (pric*) OR TITLE-ABS (toll*) AND NOT TITLE-ABS (electr*) (LIMIT-TO (SRCTYPE,"j"))

Topic 2 "Financing"

TITLE-ABS ("transport infrastructure" OR "transportation infrastructure") AND PUBYEAR > 2003 AND TITLE-ABS (financ*) (LIMIT-TO (SRCTYPE,"j"))

Topic 3 "Multimodality, interoperability and interconnectivity”

TITLE-ABS ("transport infrastructure" OR "transportation infrastructure") AND PUBYEAR > 2003 AND TITLE-ABS (multimodal*) OR TITLE-ABS (interoperab*) OR TITLE-ABS (interconnect*) (LIMIT-TO (SRCTYPE,"j"))

Topic 4 "Logistics"

TITLE-ABS ("transport infrastructure" OR "transportation infrastructure") AND PUBYEAR > 2003 AND TITLE-ABS (logistic*) AND (LIMIT-TO (SRCTYPE,"j"))

Topic 5 "Construction"

TITLE-ABS ("transport infrastructure" OR "transportation infrastructure") AND PUBYEAR > 2003 AND TITLE-ABS (construct*) AND (LIMIT-TO (SRCTYPE,"j"))

Topic 6 "Maintenance"

TITLE-ABS ("transport infrastructure" OR "transportation infrastructure") AND PUBYEAR > 2003 AND TITLE-ABS (maintenance) AND (LIMIT-TO (SRCTYPE,"j"))

Topic 7 "Environmental concerns"

TITLE-ABS ("transport infrastructure" OR "transportation infrastructure") AND PUBYEAR > 2003 AND TITLE-ABS (environmental*) AND (LIMIT-TO (SRCTYPE,"j"))

Topic 8 "Safety and security"

TITLE-ABS ("transport infrastructure" OR "transportation infrastructure") AND PUBYEAR > 2003 AND TITLE-ABS (safe*) OR TITLE-ABS (secur*) AND (LIMIT-TO (SRCTYPE,"j"))

Topic 9 "User needs"

TITLE-ABS ("transport infrastructure" OR "transportation infrastructure") AND PUBYEAR > 2003 AND TITLE-ABS (user) AND (LIMIT-TO (SRCTYPE,"j"))

Topic 10 "Resilience"

TITLE-ABS ("transport infrastructure" OR "transportation infrastructure") AND PUBYEAR > 2003 AND TITLE-ABS (resilien*) AND (LIMIT-TO (SRCTYPE,"j"))

Topic 11 "Technological changes in transport"

TITLE-ABS ("transport infrastructure" OR "transportation infrastructure") AND PUBYEAR > 2003 AND TITLE-ABS (technolog*) AND (LIMIT-TO (SRCTYPE,"j"))

Topic 12 "Communication and data transfer"

TITLE-ABS ("transport infrastructure" OR "transportation infrastructure") AND PUBYEAR > 2003 AND TITLE-ABS (communicat*) OR TITLE-ABS (ICT) AND (LIMIT-TO (SRCTYPE,"j"))

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