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Rail transport research and innovation in Europe

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

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Contents

Abstract

Adequate research and innovation (R&I) is paramount for the seamless development, testing, adoption and integration of new rail concepts and technologies. This report provides a comprehensive analysis of R&I initiatives in Europe in this field. The assessment follows a structured 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 technology, highlighting recent developments and future needs. It also provides insight from the academia and the private sector by means of focused scientific literature and patent analysis.

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Executive summary

The report presents an analysis of research and innovation (R&I) in rail transport in Europe in recent years. It focuses on European Union (EU) funded projects and it is based on the Transport Research and Innovation Monitoring and Information System (TRIMIS). It identifies progress in several thematic fields and technologies, while highlighting the policy context and market activities in Europe and beyond.

Policy context

Over the last decade, the European Commission's 2011 Transport White Paper has set the framework for the development of transport policy at EU level, including that for rail. It included goals to:

- shift road freight to rail (and inland waterways);
- shift the majority of medium-distance passenger transport to rail;
- complete a European high-speed rail network by 2050;
- improve connections for rail to airports and seaports;
- deploy the European rail traffic management system (ERTMS).

EU rail policy tends to be adopted and revised in legislative packages, with the fourth of these adopted in 2016. This contained a series of measures, covering both technical and market aspects. In addition to the measures included in the four railway packages, the EU has other legislation that covers the railway sector. The EU's main transport infrastructure structure policy, the trans-European network (TEN-T), supported by its principal EU funding mechanism the Connecting Europe Facility (CEF), defines the core network and supports the development of railway infrastructure,

The 2019 European Green Deal underlined that, in order to contribute to the aim of a climate neutral EU by 2050, all transport modes need to contribute to the necessary GHG reductions. The importance of rail in contributing to these GHG emission reductions was underlined in the context of boosting multimodal transport.

In December 2020, the Commission published the 'Sustainable and Smart Mobility Strategy', which sets the framework for the development of EU transport policy for the next decade. The strategy sets out how transport will contribute to the delivery of the aims of the Green Deal (i.e., that the EU will be climate neutral by 2050). Additionally, it sets out a number of milestones for rail transport. They include that high-speed rail traffic should double by 2030 and triple by 2050, while rail freight traffic should double by 2050.

2021 is the European Year of Rail, an initiative by the European Commission as part of the EU's efforts under the European Green Deal.

Main findings and conclusions

This report presents a comprehensive analysis of rail R&I in Europe in the last years, focusing mainly on selected EU funded projects starting from the Seventh Framework Programme (FP7) and the Horizon 2020 (H2020) Framework Programme (FP). The report identifies relevant researched technologies in European FPs and highlights the relevant policy context and the market activities both in Europe and outside. The main findings can be summarised as follows:

- There are 526 projects under the rail transport mode in TRIMIS. The highest number of rail R&I projects is related to the Strategic Transport Research and Innovation Agenda (STRIA) roadmaps of transport infrastructure, network and traffic management, and, vehicle design and manufacturing.
- The organisations from the five most active countries (Germany, Spain, France, Italy and the United Kingdom) attract almost 75% of total EU contribution directed to rail R&I projects.
- Among the top-20 researched rail technologies, eight are linked only to rail while seven are linked also to road, five to multimodal transport, three to aviation and one to waterborne transport.
- The top-5 funded technologies (with a funding of above €50 million) are:
  - collaborative logistics ecosystem;
  - self-diagnosis smart sensors and smart running gear;

  - decision support tools for infrastructure management;
  - more efficient rail wagons;
  - education and research in the rail sector.
- Research and innovation projects in rail transport field were categorised under six sub-themes:
  - On the *efficient stock design and manufacturing* sub-theme, lightweight materials and lighter smarter designs hold promising results, along with new alloys which allow for reduced energy consumption and maintenance needs;
  - For the *emissions and noise reduction* sub-theme, main railway noise sources and scenarios have been investigated, as well as improved efficiency and performance of engines;
  - On the *track and stock maintenance* sub-theme, condition monitoring for track maintenance and axle bearing have been researched, using temperature and vibration-based methods;
  - The *efficient rail operations* sub-theme covers research ranging from railway signalling and automation systems, intelligent power supply systems, obstacle detection and realistic testing of European Traffic Control System (ETCS) components;
  - For the *infrastructure management* sub-theme, improved energy management solutions were researched and applied, along with infrastructure protection against electromagnetic attacks;
  - The *Information and Communications Technologies* (*ICT) solutions to enhance the rail travel experience* sub-theme includes research on interoperability between booking and ticketing systems, mobile application development and crowd flow analysis tools.
- The number of academic publications related to rail is increasing. Among all the sub-themes, *ICT solutions to enhance the rail travel experience* presented the highest increase in publications in the last decade. As a general remark, in the last years China seems to dominate scientific outputs in rail transport research. However, Europe's performance is strong: combining the publication record of all the 27 member countries (EU27) of the EU, for most of the sub-themes the European Union is the leading entity.

— For rail related patent applications, the highest number of patents belongs to the *efficient stock design and manufacturing sub-theme*, followed by *emissions and noise reduction*. The remaining sub-themes have a similar share of patents. The increase in number of patents is relatively linear until at least 2016, taking into consideration existing delays in granting patents.

Some final considerations can be made regarding the way forward in rail R&I. A number of Shift2Rail R&I projects from the 2020 annual work plan and budget have commenced in December 2020, with findings expected in 2021 and beyond. No significant Call for Proposal is foreseen by Shift2Rail for 2021.

It is expected that Europe's Rail, the joint undertaking (JU) replacing Shift2Rail will focus on digital innovation and automation to achieve the radical transformation of the rail system needed to deliver on the European Green Deal objectives.

Related and future JRC work

This TRIMIS report on rail R&I in Europe is part of a series of reports addressing specific transport modes. This report follows one on waterborne transport (with a focus on decarbonisation) and a subsequent one on aviation. Through the continuous effort in consolidating and expanding the TRIMIS database, the TRIMIS analyses aim to better capture R&I efforts beyond the currently included funding means and to provide more accurate details on the technology assessment which will be further refined.

Quick guide

The report is structured as follows:

Section 1 gives a brief introduction. Section 2 defines the methodological approach and the research scope. Section 3 provides the current state of play in Europe. Section 4 provides an overview of the international and European policy context. Section 5 and Section 6 provide respectively a quantitative and qualitative assessment of projects on rail research in Europe. Section 7 analyses the evolution of scientific publications and patents associated. Finally, Section 8 provides the conclusions.

1 Introduction

The transport sector requires new technological developments in order to address socio-economic challenges, especially within the ever-changing complex and competitive current environment. This will be achieved through research and innovation (R&I), which allows new quality standards in relation to the mobility of people and goods. Similarly, future mobility needs to be sustainable, and at the same time, safe, comfortable and affordable for the passengers. Rail transport is an established transport mode, which meets these criteria, and has gained momentum from significant technological improvements in the last decades.

In fact, nowadays, high-speed inter-city rail services with speeds up to 350 kilometres per hour are common in Western Europe and East Asia. At the same time, peri-urban and urban rail (tram or light rail) and metro services serve millions of Europeans daily. Rail freight transport including intermodal freight cargo using standard shipping containers is also important to meet sustainability targets.

Looking at numbers, high-speed lines in Europe increased from 7870 km in 2015 to 9 169 km in 2019, with a potential to reach the length of 11 228 km[1]. In 2018, rail transport accounted for 18.7% of the total inland freight transport. In spite of the increase in the use of rail since the early 1990s, the modal share of rail for passenger transport has been relatively stable over the last 25 years. In addition, the modal share of rail for freight transport has also been relatively stable over the last 15 years, although this is lower than the level of the late 1990s [2].

Rail passenger and freight volumes in Europe in 2018 accounted for 404.3 billion passengers and 434.9 billion tonne-kilometres, an increase of 10% and 3% respectively compared to 2015 values[3]. Regarding quality of passenger service, rail in the group of the 28 EU Member States (EU28) had in the period 2014-2018 one of the lowest fatality risks among different transport modes (0.05 number/billion passenger-kilometres). In the same period, aircraft passenger fatality rate was 0.03, while coach and car fatality rates were 0.23 and 2.34 respectively[4].

From a policy perspective, over the last decade, the European Commission's (EC) 2011 Transport White Paper (European Commission, 2011) has set the framework for the development of transport policy at European Union (EU) level, including that for rail. In its ten headline goals for transport, the White Paper set a number of ambitious aims for the rail sector. These included goals to shift road freight to rail (and inland waterways), for the majority of medium-distance passenger transport to go by rail, for an increase in the number of high speed rail lines, for improved connections for rail to airports and seaports and for the deployment of the European rail traffic management system (ERTMS). EU rail policy tends to be adopted and revised in legislative packages, with the fourth of these adopted in 2016. This contained a series of measures, covering both technical and market aspects.

In May 2017, the 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 (listed below) set out common priorities to support and speed up the research, innovation and deployment process leading to technology changes in transport:

- Connected and automated transport (CAT)
- Transport electrification (ELT)
- Vehicle design and manufacturing (VDM)
- Low-emission alternative energy for transport (ALT)
- Network and traffic management systems (NTM)
- Smart mobility and services (SMO)
- Transport infrastructure (INF)

The European Commission established in 2014 the Shift2Rail Joint Undertaking (S2R JU) a public-private partnership in the rail sector to provide a platform for coordinating and to manage all rail-focused R&I actions

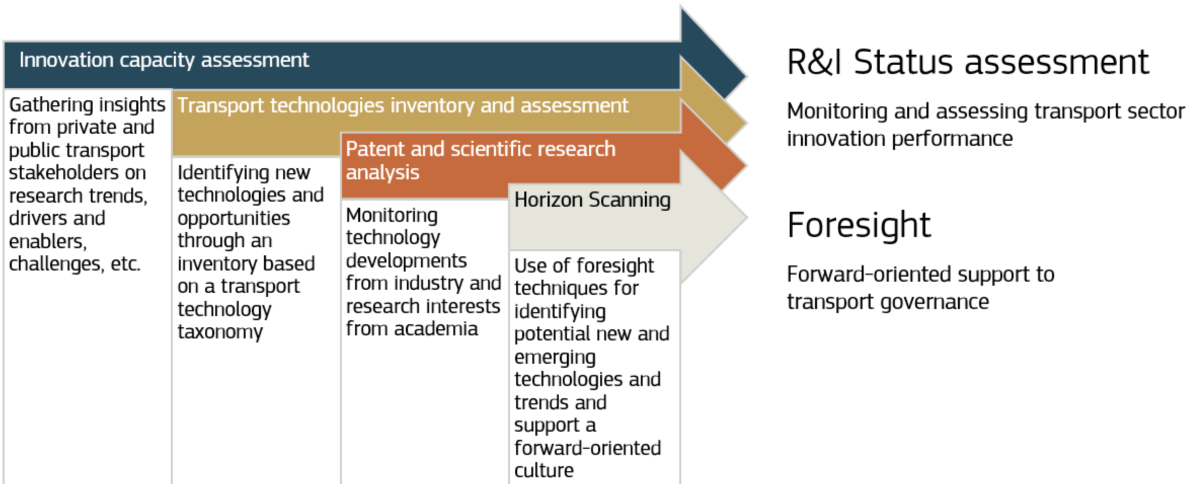
[1] https://ec.europa.eu/transport/modes/rail/market/market_monitoring_en (accessed on 2 March 2021)
[2] https://ec.europa.eu/eurostat/statistics-explained/index.php/Freight_transport_statistics_-_modal_split (accessed on 2 March 2021)
[3] https://ec.europa.eu/transport/modes/rail/market/market_monitoring_en (accessed on 2 March 2021)
[4] https://ec.europa.eu/transport/modes/rail/market/market_monitoring_en (accessed on 2 March 2021)

co-funded by the EU with a view to driving innovation in the rail sector. The Founding Members of the Joint Undertaking (JU) are the EU and eight key players from the rail industry[5]. Shift2Rail promotes the competitiveness of the European rail industry, meets EU transport needs and develops, by means of targeted R&I actions and developing the necessary technology to complete the Single European Railway Area (SERA). The activities of the Shift2Rail are structured around five asset-specific Innovation Programmes (IPs) that focus on cost-efficient trains, advanced traffic management and control, high capacity infrastructure, solutions for passengers, and, solutions for freight. These activities are supported by five cross-cutting activities. Finally, a separate Innovation Programme X (IPX) focuses on building an integrated rail system of system approach to deliver the transformational changes enabled by digitalisation and automation, supported by a Conceptual Data Model, as well as looking at disruptive technologies and exploratory research. This includes the exploration of synergies with non-traditional and/or emerging new modes of transport, such as hyperloop, a proposed high-speed surface mode of passenger and freight transport that has gained much visibility in recent years (Gkoumas and Christou, 2020).

The 2019 European Green Deal (European Commission, 2019) underlined that, in order to contribute to the aim of a climate neutral EU by 2050, all transport modes need to contribute to the necessary greenhouse gas (GHG) reductions. The importance of rail in contributing to these GHG emission reductions was underlined in the context of boosting multimodal transport. The framework for the development of EU transport policy for the next decade is set in the 2020 'Sustainable and Smart Mobility Strategy' (SSMS) (European Commission, 2020a). Among the milestones for rail transport identified in the Strategy, in order to deliver the aims of the Green Deal (i.e. that the EU will be climate neutral by 2050), is that high-speed rail traffic should double by 2030 and triple by 2050, while rail freight traffic should double by 2050.

The European Commission's Joint Research Centre (JRC) has developed the Transport Research and Innovation Monitoring and Information System (TRIMIS). TRIMIS is an integrated transport policy-support tool with a modular design that operates as a knowledge management system offering open-access information (Figure 1).

Figure 1. TRIMIS modular development



Source: Tsakalidis et al. 2020

Contrary to other transport policy-support tools, TRIMIS provides a holistic assessment of current and emerging technologies and trends and R&I capacities in the European transport sector, incorporating foresight capabilities based on transport R&I data collection, innovation capacity mapping, technological status assessment, horizon scanning, and identification of new and emerging technologies and trends (Tsakalidis et al. 2020). TRIMIS was funded under the Horizon 2020 Work Programme 2016-2017 on Smart, Green and Integrated transport (European Commission, 2017c).

Using the TRIMIS methodology, this report starts with an overview of the state of play in rail research in Europe and a policy context section. After that, as a first step, it provides a quantitative analysis of rail R&I

[5] https://ec.europa.eu/transport/modes/rail/shift2rail_en (accessed on 2 March 2021)

projects from the TRIMIS database. It also provides information on rail technologies, including their development phase, in order to help guide the development of future research priorities and policies.

Then, it provides a comprehensive analysis of selected rail R&I projects that are financed by the Seventh Framework Programme (FP7) and the Horizon 2020 (H2020) Framework Programme (FP). It does so by grouping projects under six key sub-themes, which largely cover the key areas of research on rail transport.

The analyses are integrated with findings from the Scopus research database and the TRIMIS patent database that highlight respectively research and R&I trends from academia and the private sector worldwide.

This report aims to provide an overview of the current state of play in rail research. These results should help funding organisations, policy makers and researchers to make better-informed choices to push the field forward.

2 Data sources and approach

The main goal of this report is to review targeted EU-funded rail R&I. To this aim, it was essential to establish a process for the qualitative assessment of the projects. Additional findings in this report are based on the TRIMIS methodology for the identification and assessment of technologies researched within R&I Framework projects.

Considering the above, this section provides:

1. The type of analysis and the research scope of the different sections (2.1)
2. An overview of the TRIMIS database structure and development (2.2).
3. The rail related projects in TRIMIS (2.3).
4. An overview of the TRIMIS methodology for the identification and assessment of technologies researched within R&I Framework projects (2.4).
5. The qualitative assessment methodology (2.5).

In addition to this, section 7.1 and 7.2 report briefly the steps taken for the scientific research and the patent analyses.

2.1 Type of analysis and research scope

Each chapter of this report addresses Rail R&I from a complementary perspective, with a research scope that is adjusted accordingly. Table 1 highlights the approaches used in various parts of the report to facilitate understanding and interpreting the results.

Table 1. Research scope of each chapter and section

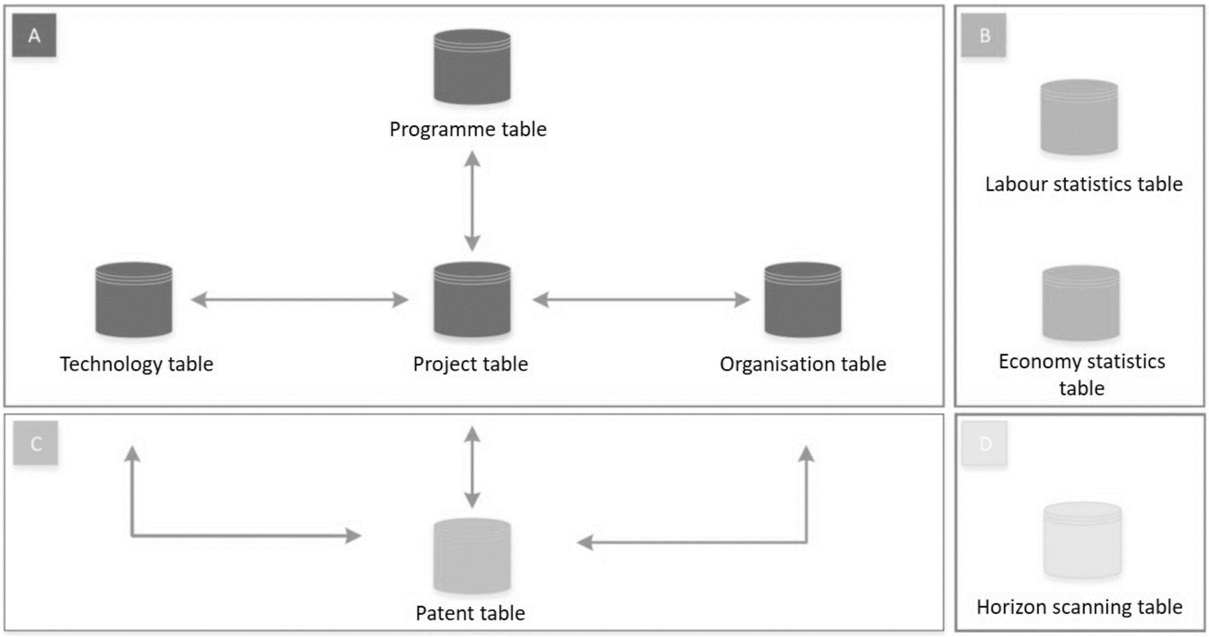
Chapter (section)	Type of analysis	Scope
Chapter 3: State of play	Literature review	Review of trends and business initiatives
Chapter 4: Policy context	Literature review	Review of policy initiatives, focusing on the EU
Chapter 5: Quantitative project analysis	Statistical analysis	Covers selected FP7 and H2020 projects that commenced between 2007 and 2020.
Chapter 5: Technology analysis	Statistical analysis	Covers all FP7 and H2020 projects in TRIMIS that developed a rail related technology between 2007 and 2020
Chapter 6: Qualitative analysis	Project reviews	In-depth analysis of a selection of FP7, H2020 and CEF projects that commenced between 2012 and 2020
Chapter 7: Scientific output analysis	Bibliometric study	Covers publications within the SCOPUS database between 2011 and 2020
Chapter 7: Patent analysis	Bibliometric study	Covers patents within the PATSTAT database between 2010 and 2018

Source: TRIMIS

2.2 TRIMIS database development

The central element of TRIMIS is its database, a relational database that incorporates information on several transport R&I dimensions (van Balen et al. 2019). It contains a continuously updated database of EU and Member State (MS) funded programmes and projects (currently around 9 000) on transport R&I (Marques dos Santos et al. 2020). Projects funded by the European FPs are retrieved through an automated data link with the Community Research and Development Information Service (CORDIS), while projects funded by MSs are inserted manually by national contact points, but also by TRIMIS users on a voluntary basis. Project inputs are then evaluated and labelled according to a series of criteria linked to the STRIA roadmap classification, the transport modes and the technologies they research, and then added to the database and published on the TRIMIS web platform (van Balen et al. 2019). Figure 2 presents the TRIMIS database structure, highlighting four different fields (A, B, C, D) with eight different tables. The database structure provides an insight into TRIMIS' current and future analytical capabilities.

Figure 2. TRIMIS database structure

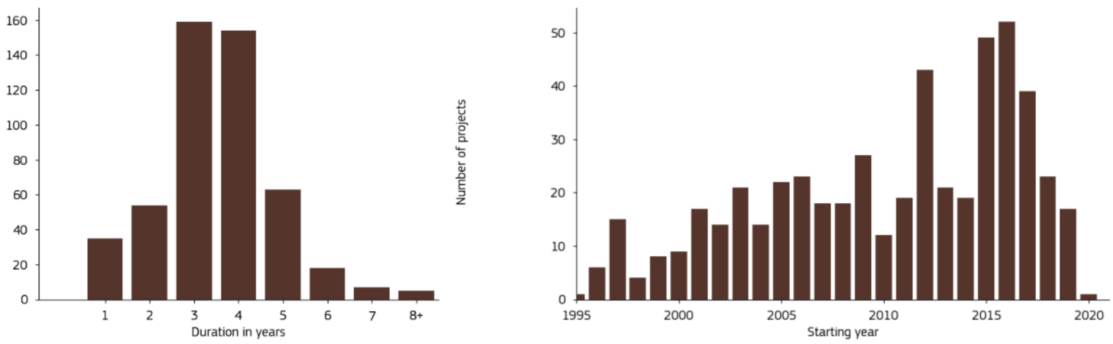


Source: van Balen et al. 2019

2.3 Rail R&I projects in TRIMIS

There are in total 526 projects labelled under the rail transport mode in TRIMIS. Most of these projects have a duration of 3 or 4 years, with a steady increase in the number of projects since 1995. The majority of projects started in the periods corresponding to the latest two European FPs, FP7 and H2020 (Figure 3).

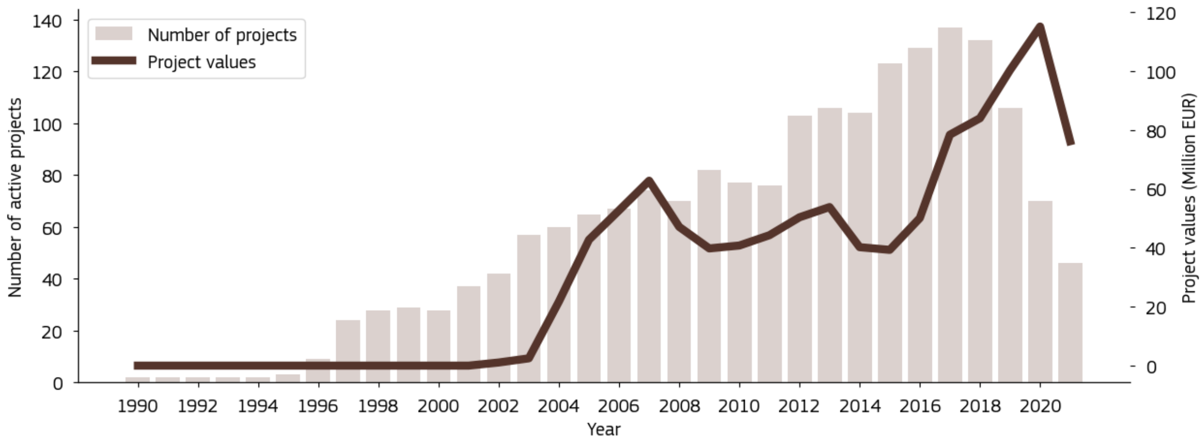
Figure 3. Rail project count by duration and starting year



Source: TRIMIS

Moreover, in Figure 4 the number of active rail projects can be seen, along with the overall project values. It is visible that values started to sharply increase after 2003, with once again peaks related to the FP7 and H2020 programmes. Funding peaked in 2020 with an annual total value for projects of a bit less than 120 million, while the maximum number of projects commenced was observed in 2017 (137 projects). The increase in 2012 is related to the Shift2Rail activities following the establishment of the JU. Similar trends are also visible when looking at the number of active projects. There has been an increase in project values and a decrease in number of active projects since 2018.

Figure 4. Number of active rail projects per year and the respective project values

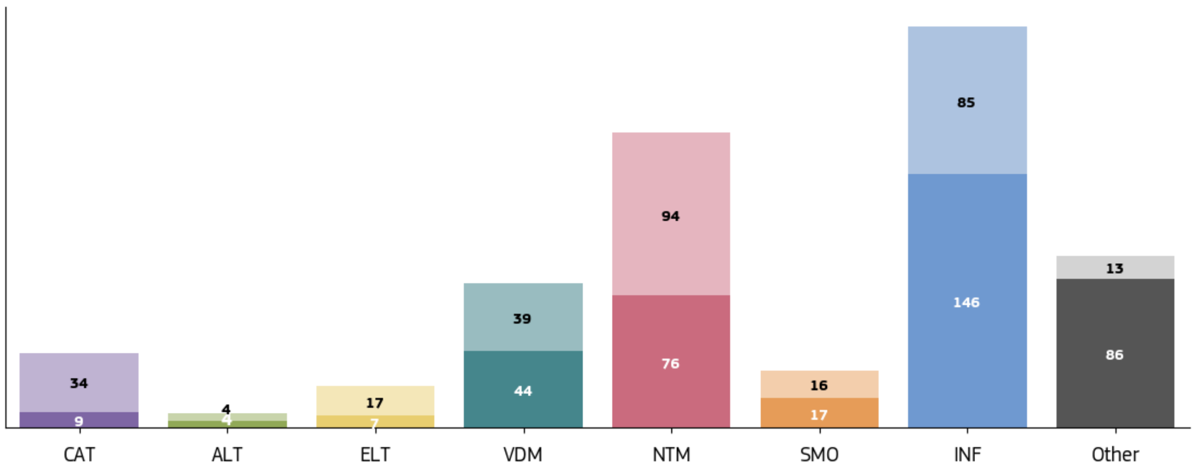


Source: TRIMIS

When analysing STRIA roadmap categories within rail projects, the roadmaps with most projects focusing on rail research can be seen.

Figure 5 shows the number of projects categorised per each roadmap, with darker colours representing projects uniquely in the roadmap and lighter colours representing projects that are linked to more than one roadmap. As it is shown, INF has the highest number of projects, followed by NTM and VDM. The latter two, however, have a high number of projects linked to multiple roadmaps. Moreover, the "Other" category also comprises a high number of projects. These are projects that are present across all STRIA roadmaps.

Figure 5. Number of rail projects per roadmap



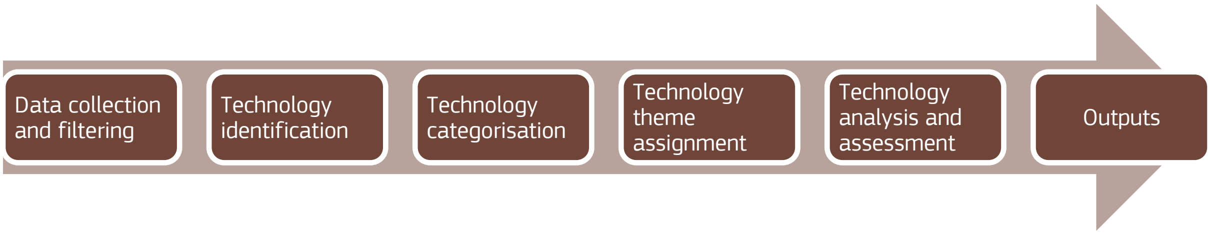
Source: TRIMIS

2.4 Identification and assessment of the technologies researched within R&I Framework Programmes

The TRIMIS technology analysis currently focuses on technologies researched in European FPs, specifically FP7 and H2020 projects from the TRIMIS database. Within these projects, technologies were identified within 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.

Figure 6 provides an overview of the methodology used for the technological assessment of the projects (Gkoumas et al. 2020).

Figure 6. Technology assessment methodological steps



Source: Gkoumas et al., 2020

The results of a study that identified technologies within European transport research projects (INTEND, 2017) were analysed. Based on this review, a standardised approach on what constituted a distinct technology and how to label them was adopted. Following this, all project descriptions were assessed and flagged when a technology was mentioned or hinted. In a next step, the full list of technologies was evaluated, and the labelling of similar technologies was aligned. Existing taxonomies, such as those under the Cooperative Patent Classification (CPC) (CPC, 2019) were used as a basis for the labels. When the technology list was established, a number of overarching technology themes was 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.

Moreover, 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 it is considered to be transparent and appropriate in the absence of technology-budget reports.

In addition, technologies in all projects have been assigned with a development phase, corresponding to the readiness of the technology at the time the project commenced. These development phases were built on a similar concept to that of the Technology Readiness Level (TRL) introduced by the National Aeronautics and Space Administration (NASA) (Héder, 2017), but the number of readiness levels (or development phases) was reduced from nine to four, reflecting the uncertainty that would be entailed in attempting to be overly precise with the allocation of a TRL, given the limited information that is usually available for the status of the technologies being researched by a project. The four TRIMIS development phases, and their relationship to the NASA TRL scale, are shown in Table 2.

Table 2. Technology readiness levels (TRLs) and TRIMIS development phase allocation

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

Source: TRIMIS, TRL scale based on European Commission, 2014

For the current assessment, the most recent TRIMIS database with entries as of December 2020 has been used. The technology database includes 871 technologies, under 46 overarching technology themes, researched in 3477 EU funded projects from FP7 and H2020. 86 technologies are linked to transport modes that include rail transport, while, 73 are linked exclusively to rail transport.

2.5 Qualitative assessment methodology

Using the data in TRIMIS, recent programmes that have funded research in railway topics have been identified. All related projects within the last two framework programmes (FP7 and H2020) have been included. In the report, each section includes a table of projects considered during the review of that sub-theme. Table 3 reports the sub-themes identified (left column), and the focus of each sub-theme (right column).

Table 3. Rail R&I sub-themes

Sub-theme	Sub-theme focus
Efficient stock design and manufacturing	Innovations in the area of rail stock (passenger trains, freight locomotives and wagons) in terms of both design and manufacturing.
Emissions and noise reduction	Research projects investigating the reduction of railway noise and emissions; through reduced energy consumption and reduced railway vibrations causing noise (including track interventions to reduce noise).
Track and stock maintenance	Technologies to predict maintenance needs of both rolling stock and the railway tracks, as well as techniques for monitoring the condition of each in real-time.
Efficient rail operations	Improving the efficiency of the railway through traffic management systems, automation and control systems.
Infrastructure management	Optimal management of railway infrastructure, which includes electrical infrastructure (overhead lines), level crossing safety and protection from potential threats.
Information and Communications Technologies (ICT) solutions to enhance the rail travel experience	Services to improve the passenger experience, including smart-ticketing systems spanning multiple transport modes and considering passengers with restricted mobility.

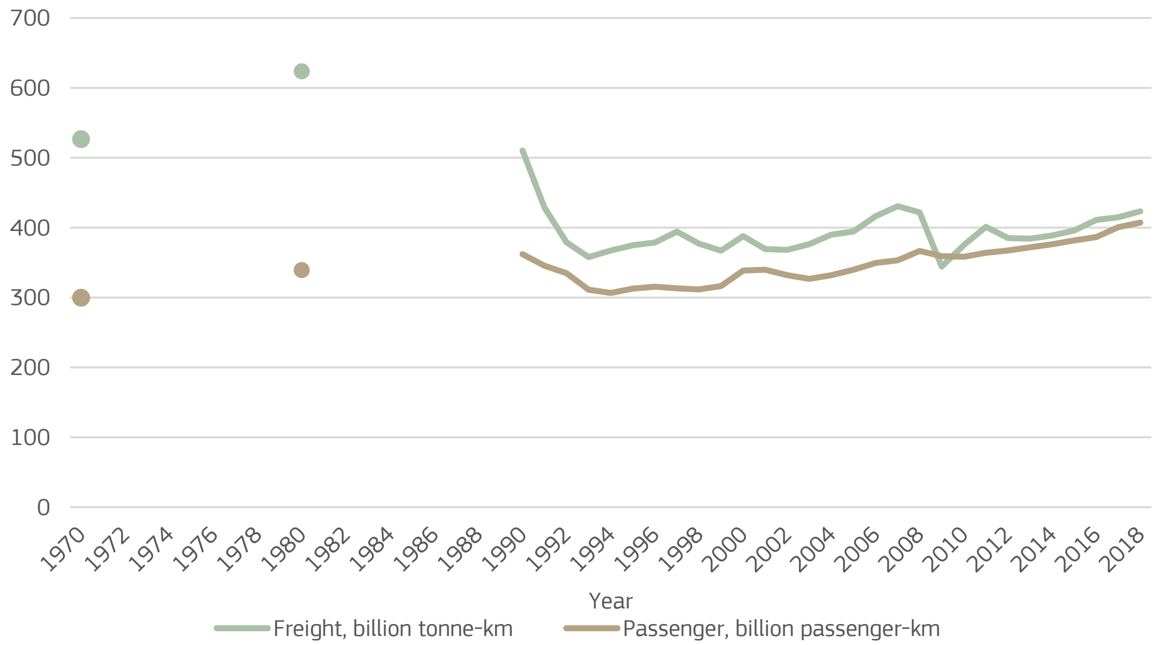
Source: TRIMIS

By adopting a clustering, it is possible to assess R&I findings focusing on specific areas of interest, provide indications 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 Current state of play of rail use and development

Railway use in the 27 member countries of the EU (EU27) has been increasing steadily since the early 2000s, although the use of rail for freight dropped as a result of the financial crisis of the late 2000s, from which it has almost recovered (Figure 7). The use of rail for passenger transport is now at levels that have not been seen in the last 50 years, whereas the use of rail for freight is still significantly below the levels of 1980 and the lower level of 1970. In spite of the increase in the use of rail since the early 1990s, its modal share has not increased in a similar way. Indeed, the modal share of rail for passenger transport has been relatively stable over the last 25 years and the modal share of rail for freight transport has been relatively stable over the last 15 years or so, although this is lower than the level of the late 1990s (Figure 8).

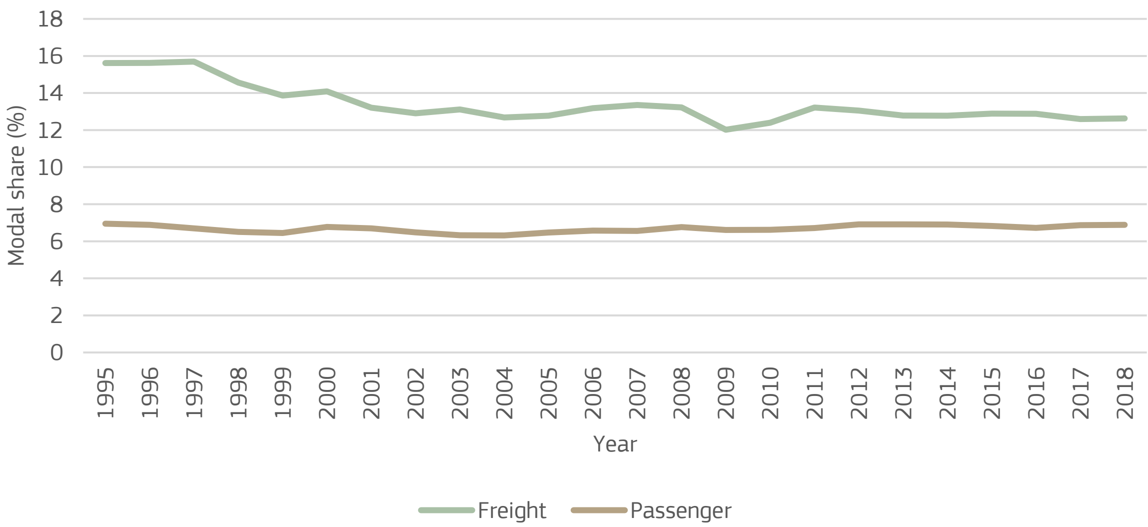
Figure 7. Railway use, freight and passenger, since 1970 (EU 27)*



* Data before 1990 partially available

Source: Data underlying "Statistical Pocket book 2020 – EU Transport in figures" (European Commission, 2020c)

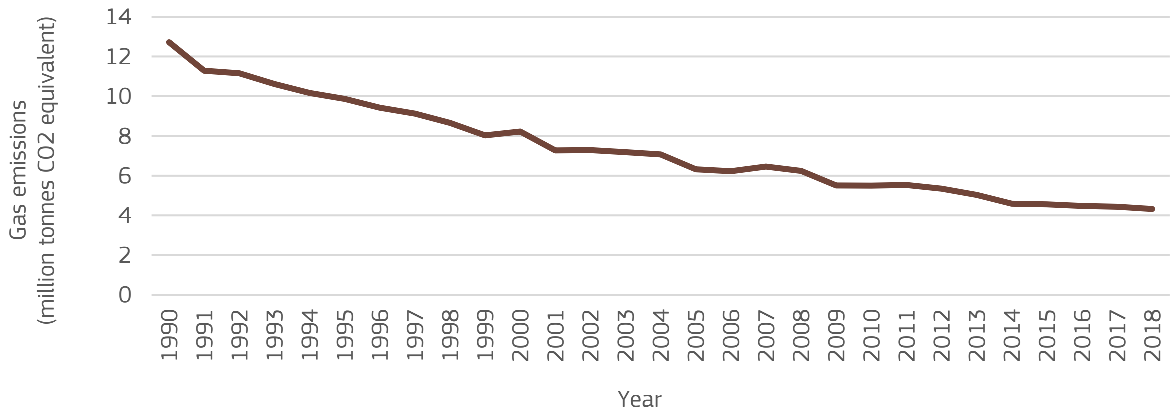
Figure 8. Railway modal share, freight and passenger, since 1995 (EU 27)



Source: Data underlying "Statistical Pocket book 2020 – EU Transport in figures" (European Commission, 2020c)

In spite of the increase in the use of rail in recent years, the sector's GHG emissions have been in decline since at least 1990 both in actual terms (see Figure 9) and as a share of transport's GHG emissions. In 1990, rail's share of transport's GHG emissions was 1.5%, which had declined to 0.4% by 2018 (European Commission, 2020c).

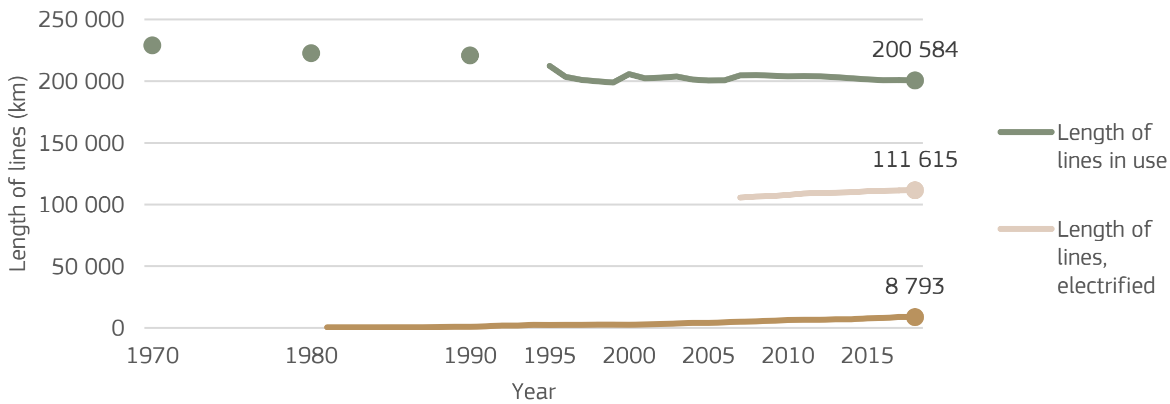
Figure 9. Railway's greenhouse gas emissions since 1990 (EU 27)



Source: Data underlying "Statistical Pocket book 2020 – EU Transport in figures" (European Commission, 2020c)

The length of railway lines in use is currently less than it was in the period from the 1970s to the 1990s, during which it declined by around 10% to their current level, which has been consistent for the last couple of decades. However, there have been a couple of positive recent trends. The first is the gradual increase in the length of railway lines that are electrified, which has been slowly increasing from 51.6% of lines in 2007 to 55.6% of lines in 2018 (Figure 10). The other trend this century has been the increase in the length of high-speed lines. Even though high-speed lines share remains relatively small as a proportion of the total number of railway lines in use (4.4% in 2018), it more than tripled from 1.3% at the beginning of the century since the beginning of the century. In addition, adding to the 8 793 km of high-speed rail lines in 2018, over 2 000 km of new high-speed rail lines are under construction, most of which will begin operation in the first half of the 2020s.

Figure 10. Length of railway lines in use, total, electrified and high speed (in km), since 1970 (EU 27)*

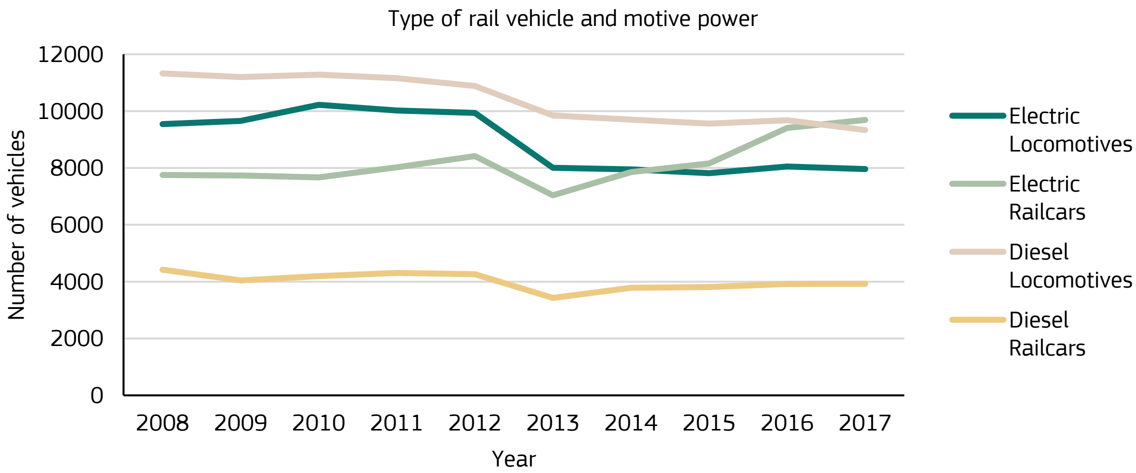


* Data before 2007 partially available

Source: Data underlying "Statistical Pocket book 2020 – EU Transport in figures" (European Commission, 2020c)

Recent changes in the number of rail locomotives and railcars by their motive power reflects the increase in the electrification of railway lines noted above. Over the last decade, the number of diesel railcars has declined slightly (although with slight increases in recent years), as has the number of diesel locomotives in use. However, the number of electric railcars has been on the increase over the same period, even though the number of electric locomotives has been declining at a similar rate to the decrease in diesel locomotives (Figure 11).

Figure 11. Number of railway locomotives and railcars, by motive power, since 2007



Source: Data underlying "Statistical Pocket book 2020 – EU Transport in figures" (European Commission, 2020c)

It is anticipated that the motive power, and the fuels, used by railways will change significantly in the next couple of decades. Many national railway companies in the EU are exploring alternatives to diesel traction for their rail networks, often in response to EU or national commitments to reduce GHG emissions more generally. French railways SNCF has announced that it intends to phase out the use of fossil fuels on its network by 2035, through a mixture of hybrid trains (using biodiesel and electricity), battery electric and hydrogen trains[6]. In Germany, DB has set itself a goal of ensuring that the traction current on its network is 100% from renewable electricity sources by 2038 and that the group will be Carbon Dioxide (CO_2)-free by 2050. In order to do this, it is looking into a range of options including battery hybrid trains, hydrogen, synthetic fuels and biofuels[7]. Austrian railways, ÖBB, has committed to being climate neutral by 2050 and is investigating how to replace its diesel vehicles, including through the electrification of lines, where possible, and by exploring the potential of battery electric and hydrogen trains[8]. In these and other countries, such as the Netherlands[9], relevant projects and trials are ongoing.

Monitoring the railway markets is necessary in order to inform policy choices. To this aim, in January 2021, the EC presented its updated report on development of the rail market[10]. This seventh in a series of reports, covers a broad range of topics, including, rail market growth, infrastructure and services available, the state of the network, congestion, and barriers to more effective rail services. The figures and information provided, highlight rail as a sustainable transport mode, and aim to feed into the activities under the European Year of Rail[11], an initiative aiming at increasing the proportion of people and goods travelling by rail, in line with the objectives of the European Green Deal.

[6] https://uic.org/events/IMG/pdf/05-sncf_h2_train_ph_clement_diffusion.pdf (accessed on 2 December 2020)
[7] https://uic.org/events/IMG/pdf/07-share-db_vestner_presentation-zurich2.pdf (accessed on 2 December 2020)
[8] https://uic.org/events/IMG/pdf/04-share-alternative_antriebe_oebb.pdf (accessed on 2 December 2020)
[9] https://www.globalrailwayreview.com/news/110138/hydrogen-train-tests-netherlands-successful/ (accessed on 4 December 2020)
[10] https://ec.europa.eu/transport/modes/rail/market/market_monitoring_en (accessed on 24 February 2021)
[11] https://europa.eu/year-of-rail/index_en (accessed on 26 March 2021)

4 Policy context

4.1 European transport policy related to rail transport

Over the last decade, the European Commission's 2011 Transport White Paper (European Commission, 2011) has set the framework for the development of transport policy at the EU level, including that for rail. The framework for the development of EU transport policy for the next decade is set in the 2020 'Sustainable and Smart Mobility Strategy' (SSMS) (European Commission, 2020a). As the existing policy framework related to rail transport has been developed in the context of the White Paper, this section starts with an overview of the way in which rail was covered in the White Paper, followed by an overview of the existing legislative framework. The section concludes with an overview of the potential policy developments for rail, as implied by the Green Deal and as set out in the SSMS.

In its ten headline goals for transport, the White Paper set a number of ambitious aims for the rail sector. These included goals to shift road freight to rail (and inland waterways), for the majority of medium-distance passenger transport to go by rail, for an increase in the length of high speed rail lines, for improved connections for rail to airports and seaports and for the deployment of ERTMS. ERTMS is the European standard for the Automatic Train Protection (ATP) and command and control systems, which creates an interoperable railway system in Europe that is safer and more efficient[12]. As part of the Single European Transport Area that was foreseen by the White Paper, it underlined the importance of addressing bottlenecks in the internal market for rail services in order to complete the SERA.

EU rail policy tends to be adopted and revised in legislative packages, with the fourth of these adopted in 2016. This contained a series of measures, covering both technical and market aspects. The legislation on technical aspects focused on the interoperability of the EU railway system, its safety and the operation of the European Union Agency for Railways (ERA), while the market elements of the package focused on opening the market for passenger rail services and introduced competitive tendering for public service contracts. The aim of these latter elements was to complete the opening of the railway market that was begun by the first railway package[13].

In addition to the measures included in the four railway packages, the EU has other legislation that covers the railway sector. The EU's main transport infrastructure structure policy, the trans-European network (TEN-T), supported by its principal EU funding mechanism the Connecting Europe Facility (CEF), defines the core network and supports the development of railway infrastructure, including ERTMS, across the EU[14]. The EU also has legislation in place on rail passenger rights[15] and on the development of a European rail network to support the competitive transport of freight by rail[16] both of which are in the process of being amended or reviewed. In addition, there is legislation to support the development of multimodal travel information systems, which covers the rail network[17], and to support the transport of freight over long distances using rail or waterborne transport (the Combined Transport Directive)[18]. The role of the ERA is becoming increasingly important in overseeing EU rail policy, as its remit covers promoting a harmonised approach to rail safety, supporting the deployment of ERTMS, improving the accessibility and use of railway information and issuing type authorisation and single safety certificates[19].

The 2019 European Green Deal underlined that, in order to contribute to the aim of a climate neutral EU by 2050, all transport modes need to contribute to the necessary GHG reductions. The importance of rail in contributing to these GHG emission reductions was underlined in the context of boosting multimodal transport. The Green Deal reiterated the importance of shifting freight from road to rail (and inland waterways), which would require measures to increase the capacity of the rail network, measures to manage it better and a potential revision to the Combined Transport Directive (European Commission, 2019).

[12] https://ec.europa.eu/transport/modes/rail/ertms_en (accessed on 24 February 2021)
[13] https://ec.europa.eu/transport/modes/rail/packages/2013_en (accessed on 2 December 2020)
[14] https://ec.europa.eu/transport/themes/infrastructure/ten-t_en; https://ec.europa.eu/inea/en/connecting-europe-facility/cef-transport (accessed on 2 December 2020)
[15] https://ec.europa.eu/transport/themes/passengers/rail_en (accessed on 2 December 2020)
[16] https://ec.europa.eu/transport/modes/rail/infrastructures/rail_freight_oriented_network_en (accessed on 2 December 2020)
[17] https://ec.europa.eu/transport/themes/its/road/action_plan/multimodal-travel-information_en (accessed on 2 December 2020)
[18] https://ec.europa.eu/transport/themes/logistics-and-multimodal-transport/multimodal-and-combined-transport_en (accessed on 2 December 2020)
[19] https://www.era.europa.eu/agency/mission-vision-and-values_en (accessed on 2 December 2020)

Focusing on the SSMS published by the Commission in December 2020, it sets out how transport will contribute to the delivery of the aims of the Green Deal (i.e., that the EU will be climate neutral by 2050). The Staff Working Document (SWD) that accompanies the strategy (European Commission, 2020b) notes that, under the baseline scenario, rail passenger demand is expected to increase by 32% between 2015 and 2030 (by 66% by 2050), driven in part by the completion of the TEN-T core network by 2030 and the comprehensive network by 2050. However, the overall baseline scenario does not meet the climate challenge posed. Therefore, the SSMS identifies a need for additional policy action to achieve the aims of the Green Deal. The Strategy sets out a number of milestones for rail transport, including that high-speed rail traffic should double by 2030 and triple by 2050, while rail freight traffic should double by 2050. Other relevant milestones were that "scheduled collective transport" travelling under 500 km should be climate neutral within the EU by 2030, while by 2050 the TEN-T will be equipped for sustainable and smart multi-modal transport. The delivery of these milestones is to be supported by relevant research to ensure that the right vehicles and fuels are supplied by industry. Policy measures relevant to rail that were proposed included:

- an action plan to boost long-distance and cross-border rail services;
- potential measures to expand the rail market;
- revisions to the regulations governing Rail Freight Corridors and the TEN-T core network corridors;
- European rules on rail noise.

In addition, there will be further deployment of ERTMS and measures to support the digitalisation and automation of the rail sector.

Finally, the EC will assess the need for regulatory actions to ensure safety and security of new technologies and concepts such as hyperloop.

4.2 European research programmes on rail transport

For the 2014-2020 programming period, R&I projects on rail transport are concentrated in the Shift2Rail Joint Undertaking[20]. The aim of taking such an approach was to provide a platform that would be the focal point of EU R&I for the rail sector and to enable the better coordination of this research for the benefit of the industry as a whole and its customers. Shift2Rail operates under the R&I funding programme for the period, Horizon 2020, which also includes some potential topics that would also be of interest to the rail industry, particularly relating to cross-modal research. The programming period of Shift2Rail is until end of 2024 by Council Regulation[21], although from a funding point of view calls for proposals can be launched until 2021 (included). In 2014, funding budget was used by the EC in a call (€52 m) rather than by Shift2Rail which was not yet setup.

Supporting demonstration activities is the priority for Shift2Rail in order to test, quantify and understand the potential of new technologies and innovations. It is hoped that these will help to deliver a step change in the sector and promote communication and collaboration within the industry. The aim is to demonstrate technologies up to TRL7 through a number of different types of project. First, there are Technology Demonstrators (TDs), which specify, develop and demonstrate a particular technology with the aim of this being tested in a laboratory or as a prototype. Second, there are Integrated Technology Demonstrators (ITDs), which bring together and test TD prototypes, and finally there are System Platform Demonstrators that aim to bring together the results of TDs and ITDs and assess their performance and potential in the wider system.

The R&I projects under Shift2Rail are undertaken within six parallel Innovation Programmes, each focusing on a different aspect of rail transport, while there are also cross cutting activities. The design of the rolling stock is the focus of Innovation Programme 1, including its traction, braking, control and monitoring systems, as well as other elements such as their doors, interiors and access systems. The aim of Innovation Programme 2 is to develop train control, command and communication systems to build the ERTMS game changers and more so that to include in the European safe train control system improved communications systems, automatic train control, virtual coupling, optimised traffic management and cyber security. Rail infrastructure is the focus of Innovation Programme 3, which aims to capitalise on the marketing opening and increased interoperability of the sector by focusing on improvements to all main infrastructure assets and the design of dynamic railway information management systems and intelligent asset management strategies, as well as

[20] https://shift2rail.org/ (accessed on 3 December 2020)
[21] http://data.europa.eu/eli/reg/2014/642/oj (accessed on 22 March 2021)

the design and operation of stations. Innovation Programmes 4 and 5 focus on activities that help the railway sector to be more responsive to the needs of its customer. Innovation Programme 4 focuses on passengers, including supporting interoperability with other modes of transport and on improving the passenger experience in relation to, for example, ticketing, booking and the provision of in-trip information, while Innovation Programme 5 covers topics on digitalisation and automation of the rail freight operations, development of a digital automatic coupler or smart freight wagon concepts and new freight propulsion concepts. The sixth and final programme, Innovation Programme X, focuses on potentially disruptive innovations, while the cross-cutting activities cover topics such as safety, smart mobility, energy, sustainability and human capital.

TRIMIS contains information on projects funded by Shift2Rail and others funded through FP7 and H2020, relevant to rail transport, but not funded through Shift2Rail. Table 4 to Table 6 show the number of projects and, where available, values for the funding sources for projects in TRIMIS with a strong relevance to rail.

Table 4. Numbers and values of rail projects funded under FP7

Funding action	Number of projects	Total funding (in € million)
FP7-Environment - Environmental research under FP7	1	9.2
FP7-ICT - Information and Communication Technologies	1	4.1
FP7-PEOPLE - Specific programme "People" implementing the Seventh Framework Programme of the European Community for research, technological development and demonstration activities	1	0.9
FP7-SECURITY - Security	3	30.3
FP7-SME - Specific Programme "Capacities": Research for the benefit of SMEs	1	1.1
FP7-SST - Sustainable Surface Transport	6	42.8
FP7-TRANSPORT - Transport (Including Aeronautics) - Horizontal activities for implementation of the transport programme	44	227.1
Total	57	315.3

Source: TRIMIS

Table 5. Numbers and values of rail projects funded under Horizon 2020 (including Shift2Rail)

Funding action	Number of projects	Total funding (in € million)
H2020-EU.1.3. - EXCELLENT SCIENCE - Marie Skłodowska-Curie Actions	1	195.5
H2020-EU.2.1. - Horizon 2020: INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies	1	18.7
H2020-EU.3.3. - Horizon 2020: SOCIETAL CHALLENGES - Secure, clean and efficient energy	1	4.0
H2020-EU.3.4. - Horizon 2020: Smart, Green and Integrated Transport	31	90.1
H2020-EU.3.4. - Horizon 2020: Smart, Green and Integrated Transport; H2020-EU.2.1. - Horizon 2020: INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies	1	3.4
Horizon2020 - Horizon2020 - The EU Framework Programme for Research and Innovation	2	7.9
Shift2Rail	103	769.9
Total	140	894.2

Source: TRIMIS

Table 6. Numbers of rail projects funded through the Connecting Europe Facility programmes

Funding action	Number of projects	Total funding (in € million)
CEF	4	11.6

Source: TRIMIS

For the next programming period, which begins in 2021, the Commission proposed a successor to Shift2Rail in the context of the new Horizon Europe R&I FP. The successor will be a 'European Partnership on Rail R&I', which will aim to accelerate the development and demonstration of innovative technologies and operational solutions, supported by the digitalisation and automation of the sector[22]. In February 2021, the EC has officially announced the successor to the Shift2Rail Joint Undertaking ("Europe's rail") as part of a proposal that would see the creation of ten new European Partnerships under the Horizon Europe programme[23]. Europe's rail will speed up the development and deployment of innovative technologies to achieve the radical transformation of the rail system and deliver on the European Green Deal objectives, while improving competitiveness, and thus support European technological leadership in rail. The Europe's Rail Joint Undertaking will have the following general objectives (European Commission, 2021):

1. contribute towards the achievement of the SERA;
2. ensure a fast transition to more attractive, user-friendly, competitive, affordable, efficient and sustainable European rail system, integrated into the wider mobility system;
3. support the development of a strong and globally competitive European rail industry.

In addition to these general objectives, the Europe's Rail JU shall have specific objectives: (i) deliver a fully integrated European railway network by design, (ii) deliver a sustainable and resilient rail system, (iii) develop an unified operational concept and a functional system architecture for integrated European rail traffic management, command, control and signalling systems, (iv) perform R&I activities related to rail freight and intermodal transport, (vi) develop demonstration projects in interested member states, and, (vii) contribute to the development of a strong and globally competitive European rail industry. The specific tasks of Europe's Rail JU will be facilitated by Master Plan prepared together with the Commission., which will form the Europe's Rail JU's Strategic Research and Innovation Agenda (SRIA). The Commission, in consultation with all relevant stakeholders, may start the preparation of the Master Plan prior to the establishment of the Europe's Rail JU.

4.3 Rail transport in non-European countries' policies

In August 2020, the China State Railway Group was reported to have announced plans to expand its rail network by 40% to over 200 000 km by 2035, which would also involve a doubling of the length of its high-speed lines to 70 000 km. Its aim is to provide a rail connection to all cities with a population of over 200 000 and a high-speed rail connection to cities with a population of over half a million. The expansion in the rail network aims to support the shifting of road traffic to the railways[24]. The associated investment will also support the development of a smart railway network in the country, supported by 5th generation mobile networks (5G) technology and the BeiDou Navigation Satellite System. These will be used to support an integrated train control system focusing first on high-speed infrastructure, followed by the rest of the network[25].

Indian Railways is also reported to be in the process of adopting a National Rail Plan, which would be the first country-wide plan that aimed to integrate and upgrade the national rail network. The plan would aim to increase the modal share of rail transport in the country from 26% to 45% by 2030. It is anticipated that the plan will contain a network plan that would inform the need for new lines, as well as the upgrading of existing routes and the modernisation of rolling stock. The increased deployment of artificial intelligence (AI) is also foreseen to support the operation of the network, to use its capacity more efficiently and to improve the quality of its services[26]. The country is also exploring the implementation of various high-speed rail lines, with the first expected to come into operation in 2023[27].

[22] https://shift2rail.org/ (accessed on 3 December 2020)
[23] https://ec.europa.eu/commission/presscorner/detail/en/ip_21_702 (accessed on 3 March 2020)
[24] https://www.railwaypro.com/wp/china-unveils-its-2035-rail-plan (accessed on 3 March 2020)
[25] https://www.globaltimes.cn/content/1197628.shtml (accessed on 3 March 2020)
[26] https://www.railjournal.com/freight/indian-railways-to-adopt-national-rail-plan/ (accessed on 3 December 2020)
[27] https://www.iea.org/reports/the-future-of-rail (accessed on 3 December 2020)

Meanwhile, in September 2020 Brazil has taken the first step to revitalise its rail network for passenger transport, through an agreement between the Ministry of Infrastructure and a national association, which paves the way for the development of a National Passenger Rail Transport Policy and a Passenger Rail Transport Development Plan[28]. Similarly, South Africa is planning to take steps to revive its rail network by enabling greater private sector participation in the sector[29].

In Japan, the development of its high-speed *Shinkansen* railway network is continuing. The network is being developed in line with legislation from 1973, and new lines are currently being developed in different parts of the country[30]. In the United States (US), the Federal Railroad Administration, which is part of the US Department of Transportation (DOT), aims to enable the "safe, reliable and efficient movement of people and goods". It has a Research and Development Office that has 10 programmes, the main focus of which is to improve safety, in line with the DOT's goal[31]. Similarly, in Canada, the focus is on rail safety[32], although the potential role of the national rail network in contributing to reducing Canada's contribution to climate change, particularly in terms of taking freight off the roads, has been noted[33]. Australia is still actively developing its rail network by focusing on a number of specific projects, including exploring the potential for high-speed rail[34].

In July 2020, the US DOT released Pathways to the Future of Transportation - A Non-Traditional and Emerging Transportation Technology Council Guidance Document to provide a framework for the Department's approach toward transformative technologies, including hyperloop[35].

[28] http://www.railpage.com.au/news/s/brazilian-passenger-rail-revival-agreement (accessed on 3 December 2020)
[29] https://www.pinsentmasons.com/out-law/analysis/liberalising-rail-network-south-africa (accessed on 3 December 2020)
[30] https://www.lexology.com/library/detail.aspx?g=9e2df85c-ae6a-4f0c-b14b-169aa4d4f67c;
https://www.jrailpass.com/blog/future-of-japanese-trains; https://www.jrtt.go.jp/english/construction/ (all accessed on 22 April 2021)
[31] https://railroads.dot.gov/research-development/program-areas/program-areas (accessed on 3 December 2020)
[32] https://tc.canada.ca/en/rail-transportation (accessed on 3 December 2020)
[33] https://www.railcan.ca/wp-content/uploads/2016/10/RAC_ParliamentGuide_EN.pdf (accessed on 3 December 2020)
[34] https://www.infrastructure.gov.au/rail/; https://www.artc.com.au/projects/ (accessed on 3 December 2020)
[35] https://www.transportation.gov/nettcouncil (accessed on 25 February 2021)

5 Quantitative assessment of rail research

This chapter provides an overview of rail transport research projects present in TRIMIS, first showing an overall assessment of the projects, and then presenting an analysis on recent projects related to the sub-themes introduced in Chapter 2. Additionally, an assessment of the technologies research in R&I projects is also carried out.

5.1 Rail R&I sub-themes

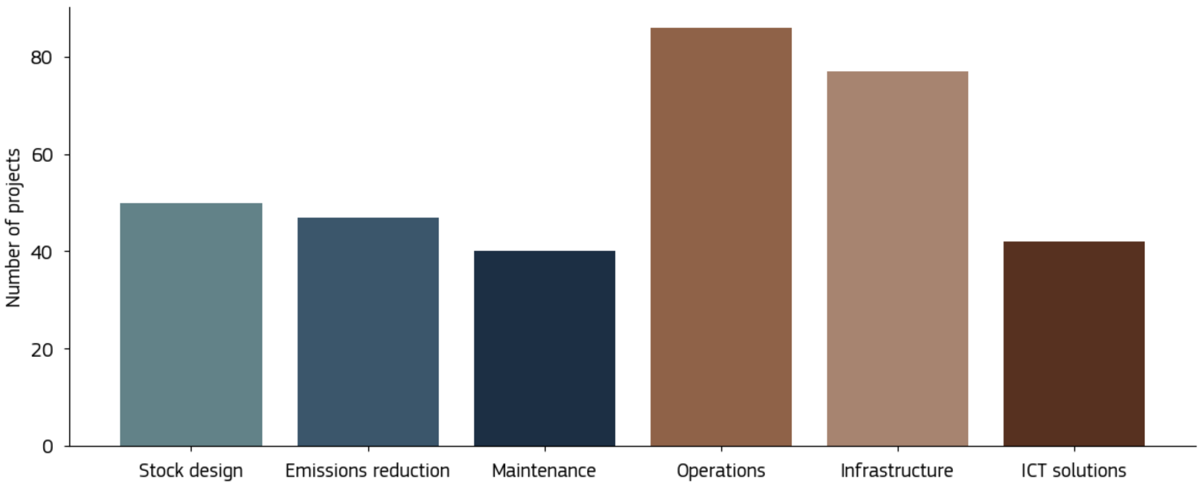
As described in Section 2.5, recent rail R&I projects were selected and categorised under six distinct sub-themes. Their names, short names and descriptions are the following:

1. Efficient stock design and manufacturing (**stock design**): Innovations in the area of rail stock (passenger trains, freight locomotives and wagons) in terms of both design and manufacturing.
2. Emissions and noise reduction (**emissions reduction**): Research projects investigating the reduction of railway noise and emissions; through reduced energy consumption and reduced railway vibrations causing noise (including track interventions to reduce noise).
3. Track and stock maintenance (**maintenance**): Technologies to predict maintenance needs of both rolling stock and the railway tracks, as well as techniques for monitoring the condition of each in real-time.
4. Efficient rail operations (**operations**): Improving the efficiency of the railway through traffic management systems, automation and control systems.
5. Infrastructure management (**Infrastructure**): Optimal management of railway infrastructure, which includes electrical infrastructure (overhead lines), level crossing safety and protection from potential threats.
6. ICT solutions to enhance the rail travel experience (**ICT solutions**): Services to improve the passenger experience, including smart-ticketing systems spanning multiple transport modes and considering passengers with restricted mobility.

For the sub-theme assignment, solely recent projects were selected, from FP7 and H2020 calls (including Shift2Rail). There were 195 projects selected for the exercise in total (shown in Annex 1, together with four CEF projects), which were assigned to one or more sub-themes; projects that cover more than one sub-theme are assigned to both groups.

Figure 12 shows the number of projects belonging to each sub-theme. It is visible that the sub-themes with the largest number of projects are *operations* and *infrastructure*, which is in line with the numbers from Figure 5 related to the NTM and INF roadmaps. There is a relatively similar number of projects for the remaining sub-themes. Additionally, the project values per sub-theme can also be analysed.

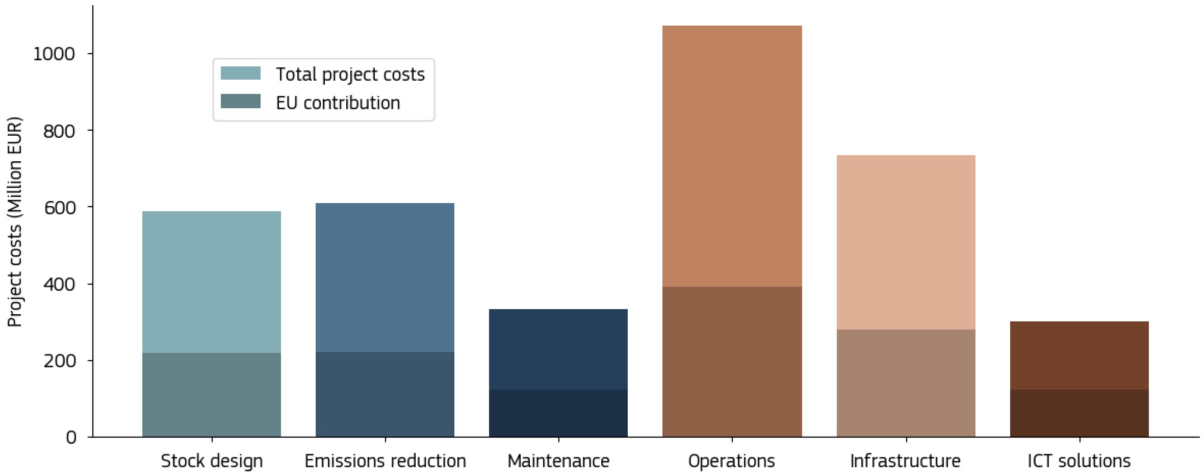
Figure 12. Number of projects per rail research sub-theme



Source: TRIMIS

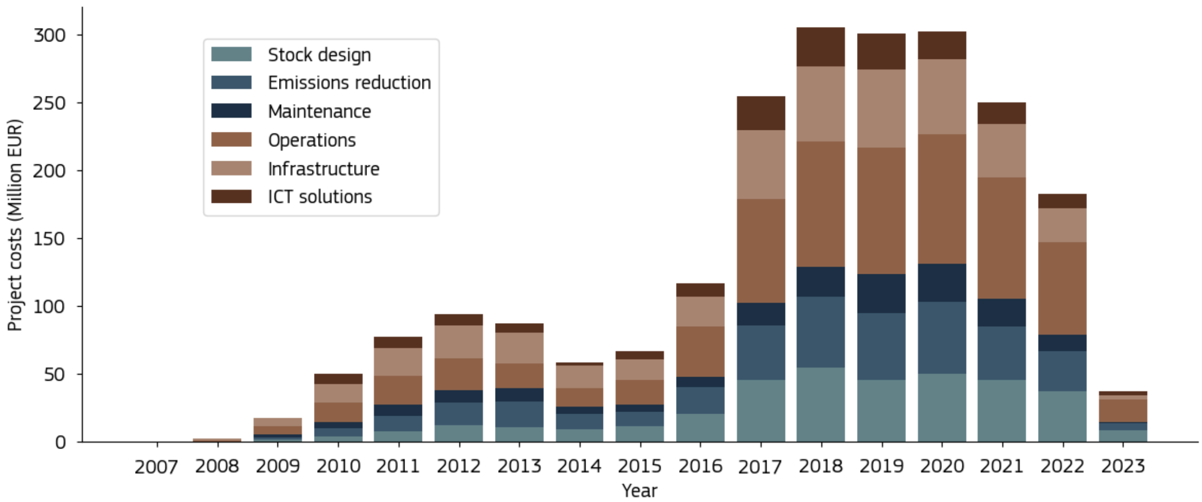
Figure 13 shows the project values for each sub-theme, with darker colours representing total project values and lighter colours representing the EU contribution. The *operations* sub-theme has the highest project values, followed by *infrastructure*. The yearly breakdown of project costs per sub-theme is shown in Figure 14, where it can be seen that the relative proportion for each sub-theme does not change substantially over the years, with the exception of the *operations* sub-theme, which has a higher share of project values after 2015, coinciding with the beginning of the H2020 FP.

Figure 13. Project values of projects per rail research sub-theme



Source: TRIMIS

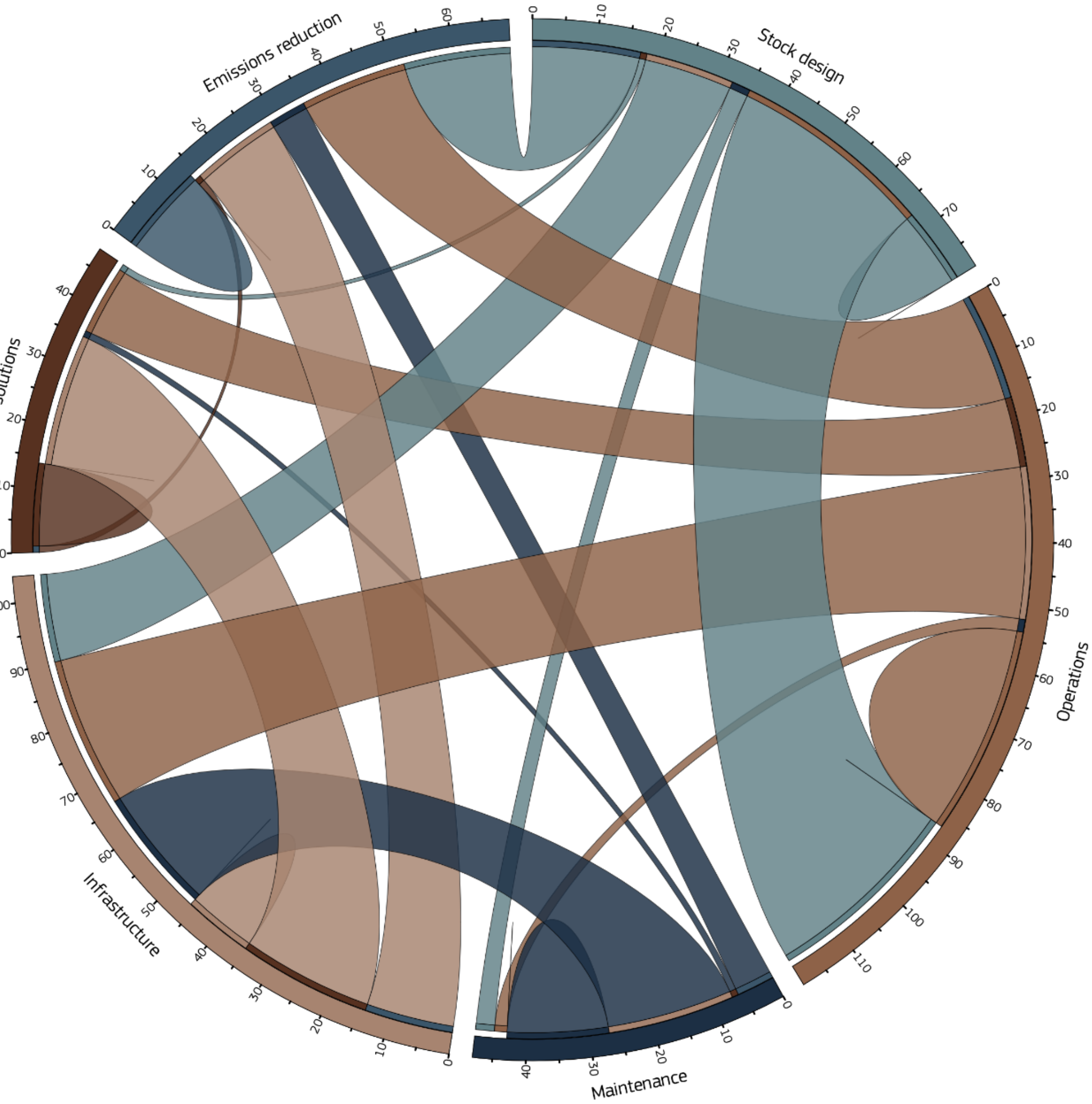
Figure 14. Yearly project values of projects per rail research sub-theme



Source: TRIMIS

Since each project can be tagged with more than one sub-theme, an exercise has been carried out to understand the relations between each sub-theme. Figure 15 shows a chord diagram representing the relation between sub-theme categorisations. Connections between two sub-themes represent projects that are belong to both sub-themes, with the thickness being related to the number of projects.

Figure 15. Relation between sub-theme categorisations[36]

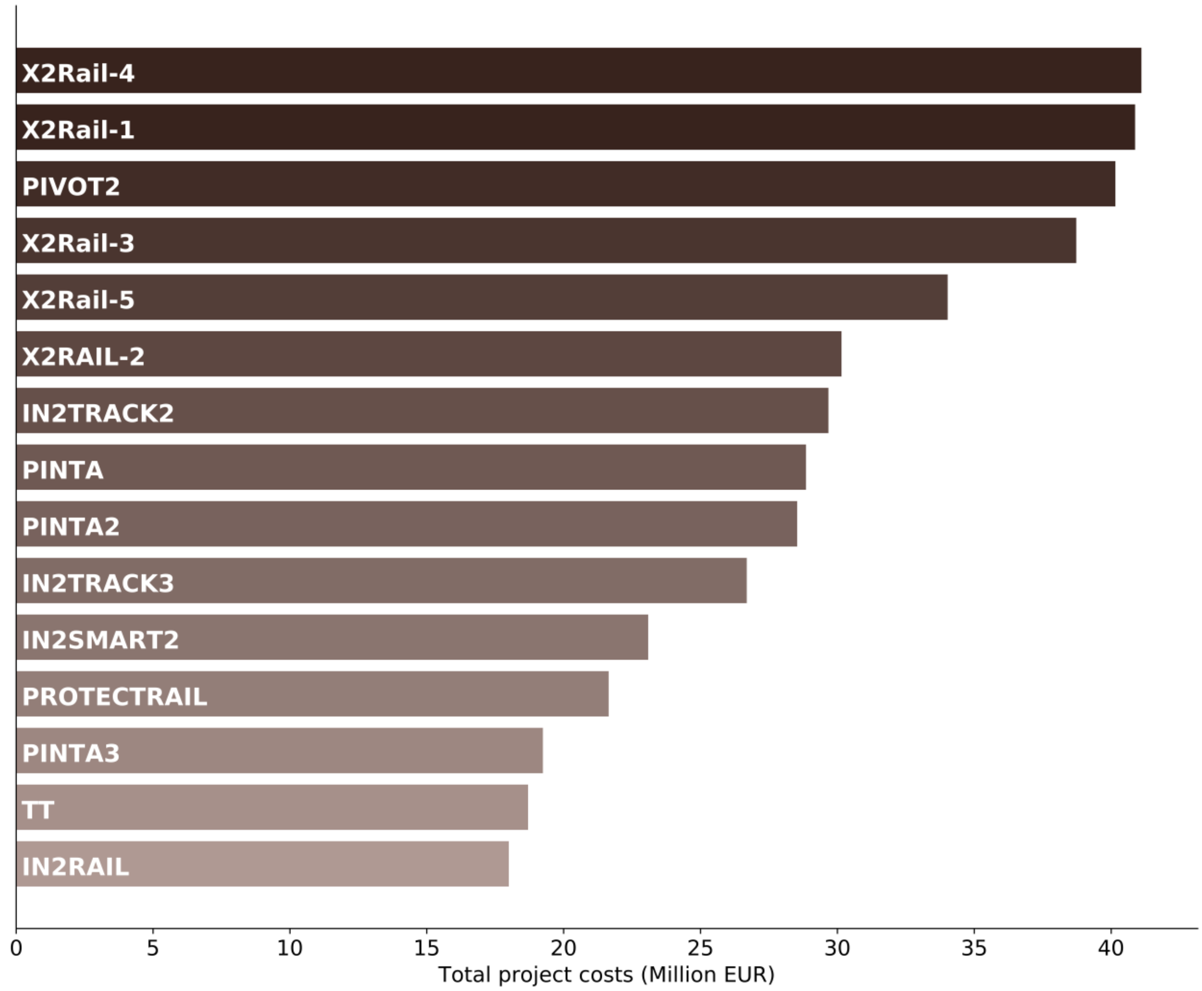


Source: TRIMIS

Finally, the top 15 projects with respect to their total project values are shown in Figure 16.

[36] This diagram was created using the Circos online tool http://mkweb.bcgsc.ca/tableviewer/docs/ (accessed on 2 March 2021)

Figure 16. Top 15 rail research projects



Source: TRIMIS

5.2 European countries involvement

The analysis of an involvement of organisations from MS and the United Kingdom (UK) is narrowed to the projects co-financed from EU funds through various European funding schemes. The analysis includes UK as it continues to participate in programmes funded under the current 2014-2020 Multiannual Financial Framework until their closure[37]. The comprehensive list of all rail R&I projects which started before the end of the year 2020 contains 195 entries funded by the FP7 and H2020 (including Shift2Rail) funding schemes. The CORDIS database is used as a source of information regarding the participating organisation place of origin, the participant role (partner or coordinator) and the amount of EU contribution directed to entities from a particular country. The geolocation procedure contains three subsequent steps.

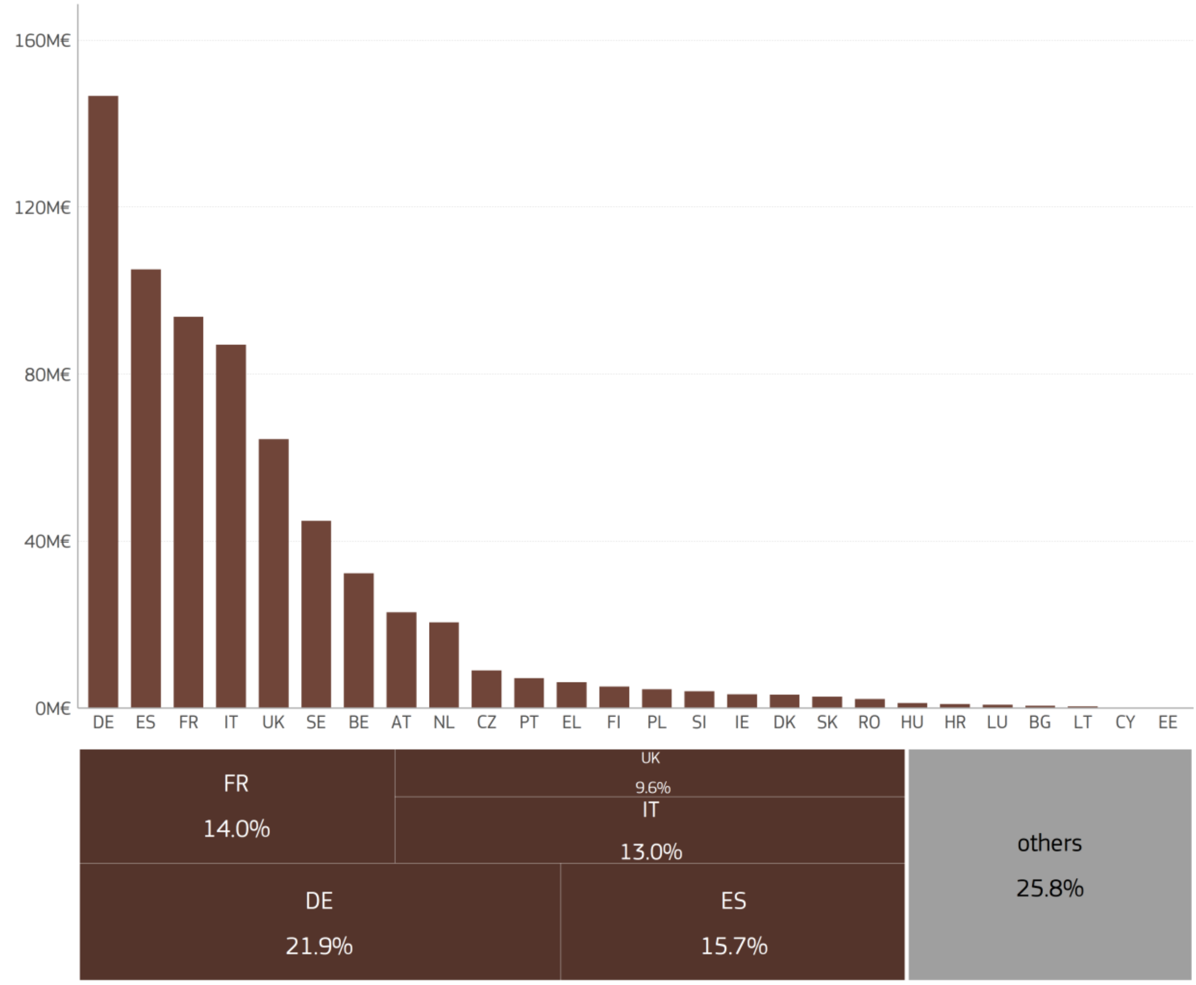
1. The first one, uses EUROSTAT's correspondence tables[38] which contain links between postcodes and Nomenclature of Territorial Units for Statistics (NUTS) level 3 codes (NUTS3). Postcodes are generally available in CORDIS database, however, some records are misspelled, have non-standard format or contain missing data. In total, the first step enables to geolocate approximately 70%, and after automatised correction of postcodes' formatting (removed unnecessary spaces, replaced dashes by spaces etc.) – nearly 90% of all the organisations.

[37] https://www.gov.uk/government/publications/continued-uk-participation-in-eu-programmes/eu-funded-programmes-under-the-withdrawal-agreement (accessed on 2 March 2021)
[38] https://ec.europa.eu/eurostat/web/nuts/correspondence-tables/postcodes-and-nuts (accessed on 2 March 2021)

2. The second step uses a name of the city (also available in the address data in CORDIS) trying to link this name to NUTS3 and LAU2 unit names.
3. In the last step, the remaining 3% of records are manually linked to the proper NUTS3 region.

Figure 17 shows the total EU contribution acquired by all organizations from a given country for all analysed R&I projects. Organisations from the five most active countries attract almost 75% of total EU contribution directed to rail R&I projects. German entities, with acquired €147 million of are the leaders in this register, followed by Spain, France, Italy and the UK. Central and East European countries have the lowest participation rates and in consequence, organisations from these countries receive substantially less funding.

Figure 17. Total EU contribution per country

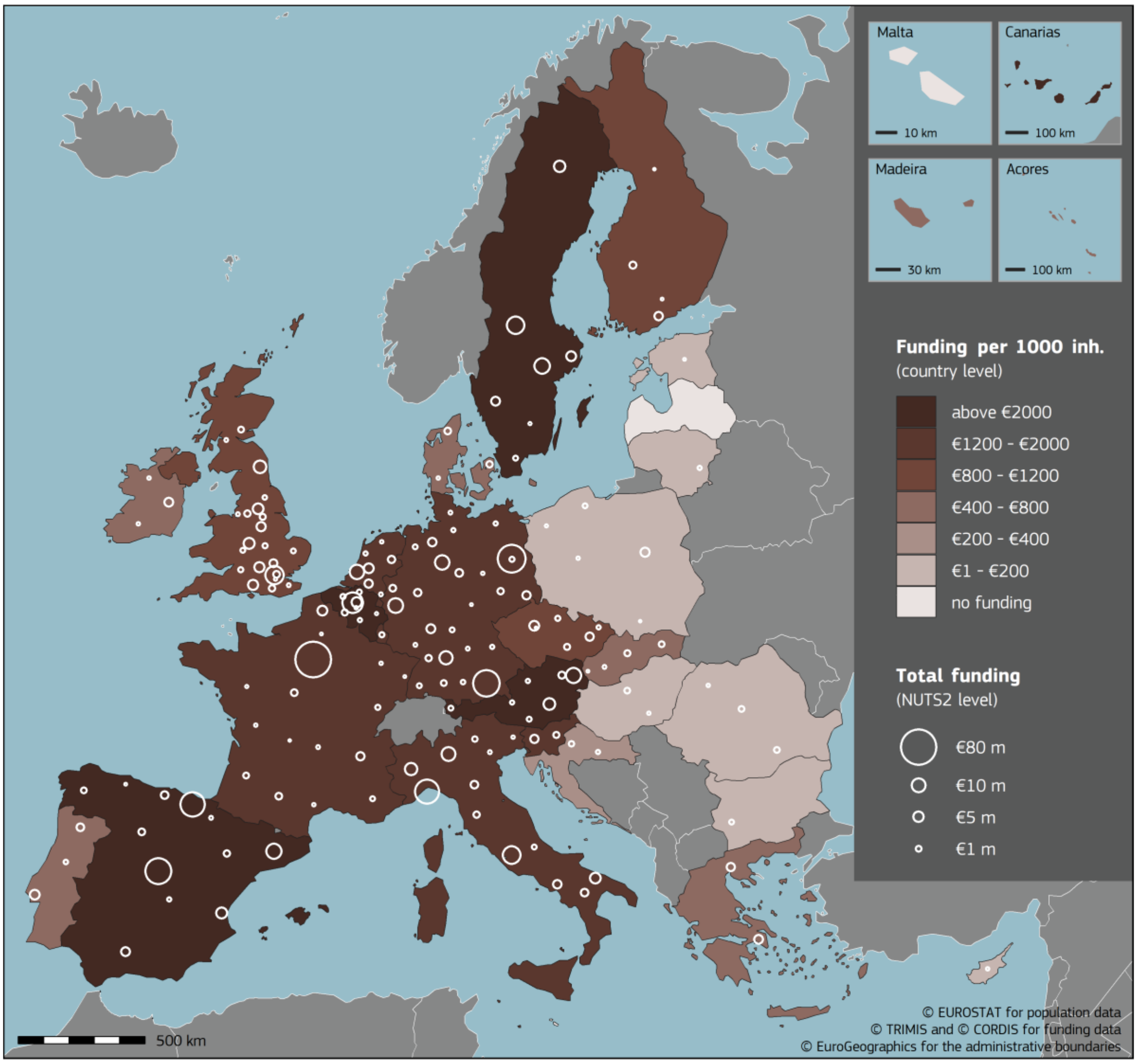


Abbreviations - DE: Germany; ES: Spain; FR: France; IT: Italy; UK: United Kingdom; SE: Sweden; BE: Belgium; AT: Austria; NL: Netherlands; CZ: Czechia; PT: Portugal; EL: Greece; FI: Finland; PL: Poland; SI: Slovenia; IE: Ireland; DK: Denmark; SK: Slovakia; RO: Romania; HU: Hungary; HR: Croatia; LU: Luxembourg; BG: Bulgaria; LT: Lithuania; CY: Cyprus; EE: Estonia

Source: TRIMIS

The lower level of participation of organizations from Eastern Europe is even more visible in Figure 18, regardless it is related to the population (choropleth layer) or in absolute terms (bubble map). In case of the latter, the map shows high concentration of EC contribution directed to regions of Belgium, Western part of the Netherlands, and the UK. Moreover, the highest amount of funding goes to organisations located in the NUTS2 regions with state capitals (Madrid, Paris, Berlin, among others) as well as some other bigger metropolitan areas of Western and Central European countries (e.g. Bilbao, Genova, Munich).

Figure 18. Distribution of EC contribution to rail R&I projects in EU MSs and UK and their regions

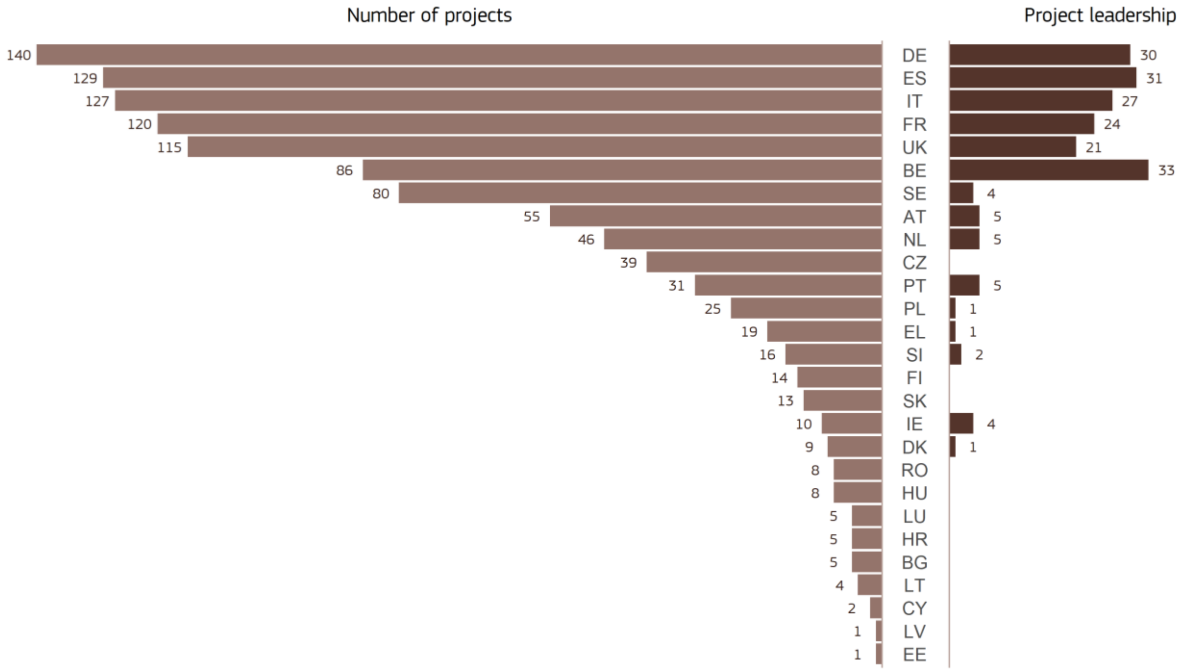


Source: TRIMIS

There are in total 953 organisations involved in 194 analysed projects, out of which 898 are located within EU27 or the UK. The countries with the largest portfolio of different organizations involved in the rail R&I projects are Germany and Spain (131 and 130 different organisations, respectively), Italy (110) and France (96).

Figure 19 shows, on the left-hand side, the number of projects with at least one partner from a given country involved and on the right-hand side, number of projects led by an organisation from a country. Organisations from the five countries the most participated in the analysed rail R&I projects: Germany, Spain, Italy, France and the UK. Even though representatives of these countries also most often took the responsibility of leading the consortium, Belgium is the country with the highest number of led projects. Moreover, there is a clear division between these six countries and any other, in terms of leading a consortium: organisations from only nine other countries led projects, but in any case, no more than five.

Figure 19. Number of projects with a partner from a given country (left) and projects led

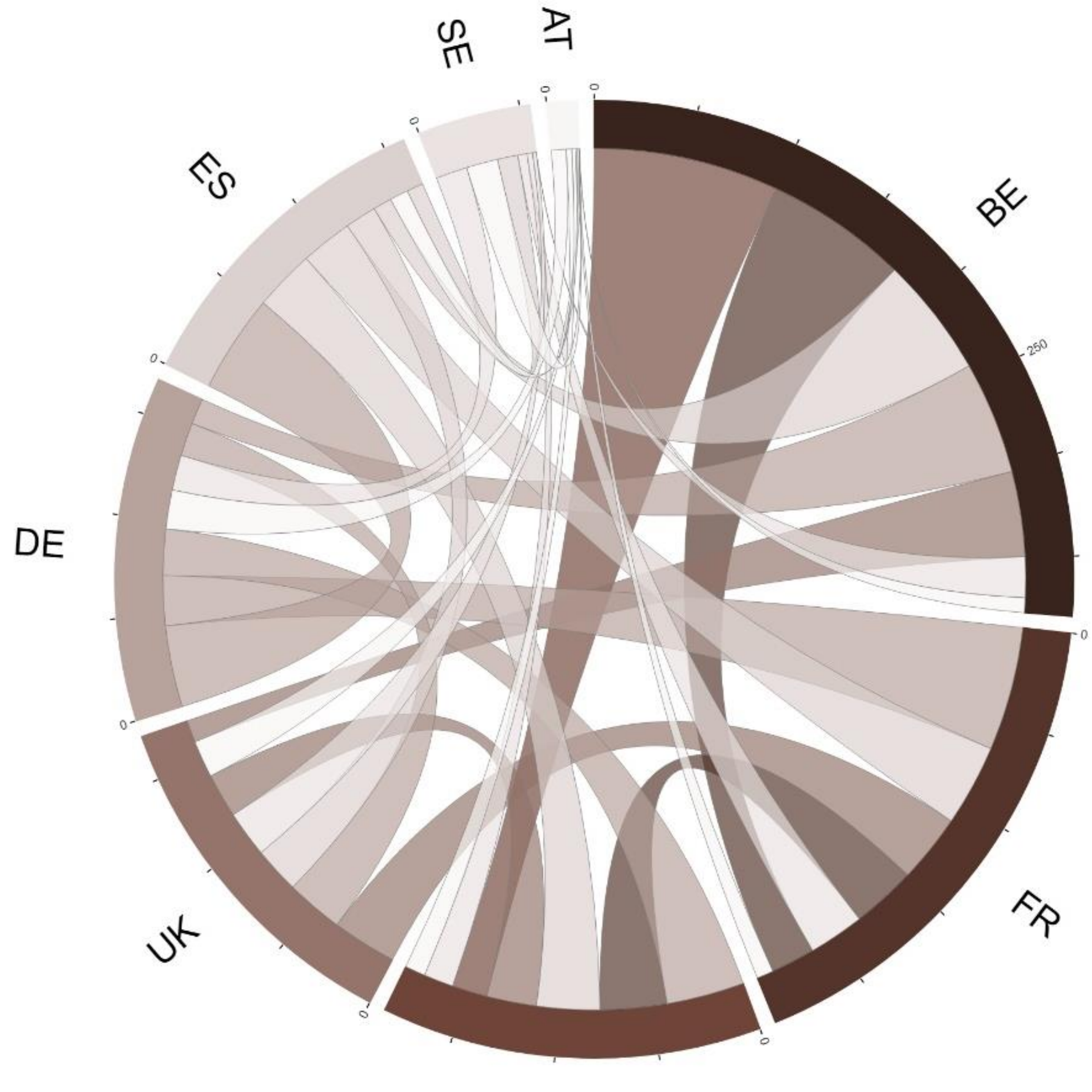


Source: TRIMIS

Figure 20 shows main collaboration links between leaders of consortium and project partners located in different countries (organisations from eight the most active countries are included). The presented chord diagram is a directional one (i.e., not a symmetric), which means that the width of the arc at ends indicates number of partners in projects coordinated by an organisation from a given country. On one hand, it shows significant imbalance in leadership involvement between Belgium entities and organisations from other countries. For example, there is much more project partners from Italy, France, Spain or Germany in projects led by Belgium entities, than other way round (Italy: 100 vs 19; France: 77 vs 24; Spain: 65 vs 10; Germany: 61 vs 14 respectively). On the other hand, there is relative equilibrium between partners from other countries, and usually the number of partners in projects led by representative of a given country are similar.

The high number led projects by Belgium's actors is related to a very high activity of the Association of the European Rail Industry (UNIFE) – this institution alone led more projects than all organisations from France or the UK. It took part in roughly 25% of all analysed R&I projects – only German's DB participated in comparable number of projects (see Table 7). These two organisations are closely followed by a group of entities which took part in more than 30 projects each. This data shows that relatively few organizations actively participated in many projects. Moreover, these high numbers of projects implemented with participation of a particular organization were possible due to the fact that rail projects were realized by large consortia. Each project was realized by 12.8 project partners on average, however the largest ones involved around 50 organizations. On the contrary, more than 600 organisations (67% of all organisations involved) took part in only one project and roughly 86% of them – in no more than three. Table 7 shows also, that high activity, or even responsibility of leading projects, not necessarily correlates with received high EU funding contribution. UNIFE mentioned above received approximately third part of the total contribution received by the most funded one, even though it participates more in projects. Additionally, the table specifies data for projects organized within S2R.

Figure 20. Collaboration links between project leader and project partners located in different countries*



* Tick marks at every 50 in the range

Source: TRIMIS

Table 7. Top 10 organisations by number of projects.

Short name	Country	Number of projects	Number of projects led*	Total EU contribution* (in € million)
UNIFE	BE	52 S2R: 23	25 (1) S2R: 11	8.7 (15) S2R: 2.7
DB	DE	51 S2R: 33	4 (6) S2R: 4	23.3 (3) S2R: 19.3
TRV	SE	42 S2R: 28	5 (3) S2R: 5	17,7 (4) S2R: 17,7
SNCF	FR	41 S2R: 29	0 (no projects led)	8.2 (17) S2R: 7.7
UIC	FR	40 S2R: 17	11 (2) S2R: 2	11.1 (10) S2R: 2.4
STS	IT	39 S2R: 26	5 (3) S2R: 3	24.9 (2) S2R: 21.9
ALS	FR	36 S2R: 19	4 (6) S2R: 4	27.4 (1) S2R: 21.7
NR	UK	35 S2R: 21	3 (12) S2R: 3	17.5 (5) S2R: 17.5
DLR	DE	26 S2R: 19	3 (12) S2R: 3	8.9 (14) S2R: 5.7
SIE	DE	24 S2R: 24	0 (no projects led)	11.5 (9) S2R: 11.5

* rank in the category in the brackets. Bottom line shows data exclusively for S2R projects
Abbreviations: UNIFE: Union des Industries Ferroviaires Europeennes; DB: Deutsche Bahn; TRV: Trafikverket; SNCF: Société nationale des chemins de fer français; UIC: Union internationale des chemins de fer; STS: Hitachi Rail STS S.p.A.; ALS: Alstom Transport SA; NR: Network Rail Infrastructure Limited; DLR: Forschungszentrum der Bundesrepublik Deutschland für Luft- und Raumfahrt; SIE: Siemens AG (Siemens Aktiengesellschaft).

Source: TRIMIS

5.3 Assessment of technologies in R&I projects

The analyses presented focus on the overall 'top-20' technologies relevant to rail in terms of total investments and the development phases of rail specific technologies as identified in FPs.

The radial structure of Figure 21 highlights the key metrics of the 'top-20' technologies in terms of total funding.

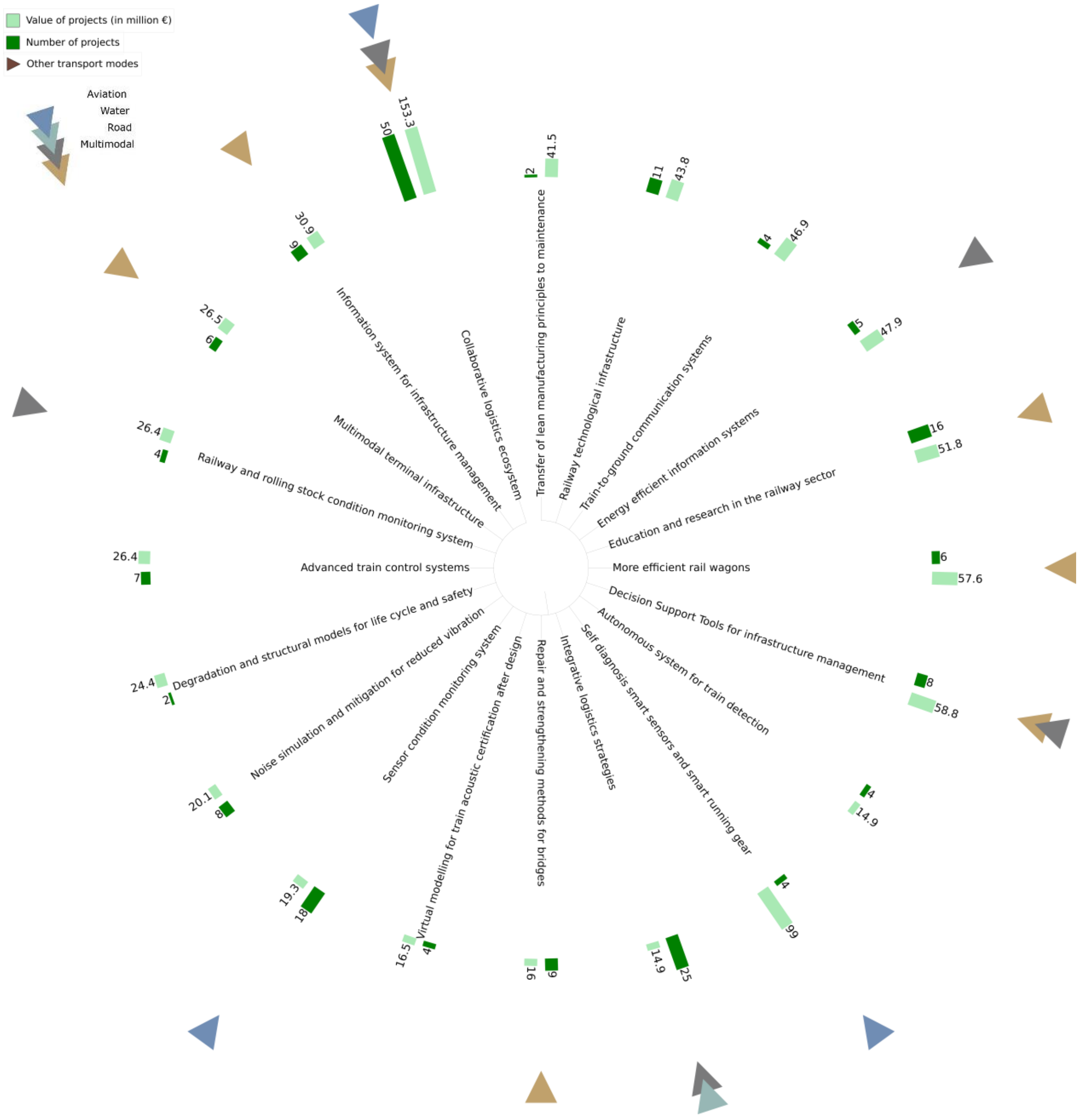
The metrics analysed are:

- "Value of projects": 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 projects": the number of projects that have researched the technology;
- "Other transport modes": technologies researched also in projects focusing on other transport modes (aviation, water, road, multimodal).

The first two metrics highlight the combined effort that has been put into the technology. The third indicator, highlights the relevance of the specific technology to a broader area of research. Principal aspects of this analysis are given below.

Among the top-20 rail technologies, eight are linked only to rail while seven are linked also to road, five to multimodal transport, three to aviation and one to waterborne transport. Five technologies received each a funding of above 50 million: *collaborative logistics ecosystem*, *self diagnosis smart sensors and smart running gear*, *Decision Support Tools for infrastructure management*, *more efficient rail wagons*, and, *education and research in the railway sector*. Those technologies linked to more transport modes are likely to give a partial view on rail research. This is the case of *self diagnosis smart sensors and smart running gear* (linked to all transport modes) and the OCEAN12 project (accounting for the majority of allocated budget) which, although focuses on aviation and road transport, may have applications in all modes. In addition, *education and research in the railway sector*, adopts a broader scope and focuses on coordinating research projects within the railway sector. It is researched in 16 projects such as IN2SMART2, which aims to deliver innovative asset management focusing mainly on tactical and operational levels, and MaaSive, which aims to promote more competitive railway passenger and freight services and improve railway travel experience focusing on integrating new technologies.

Figure 21. Top-20 rail technologies in terms of total value and connection with other transport modes[39]



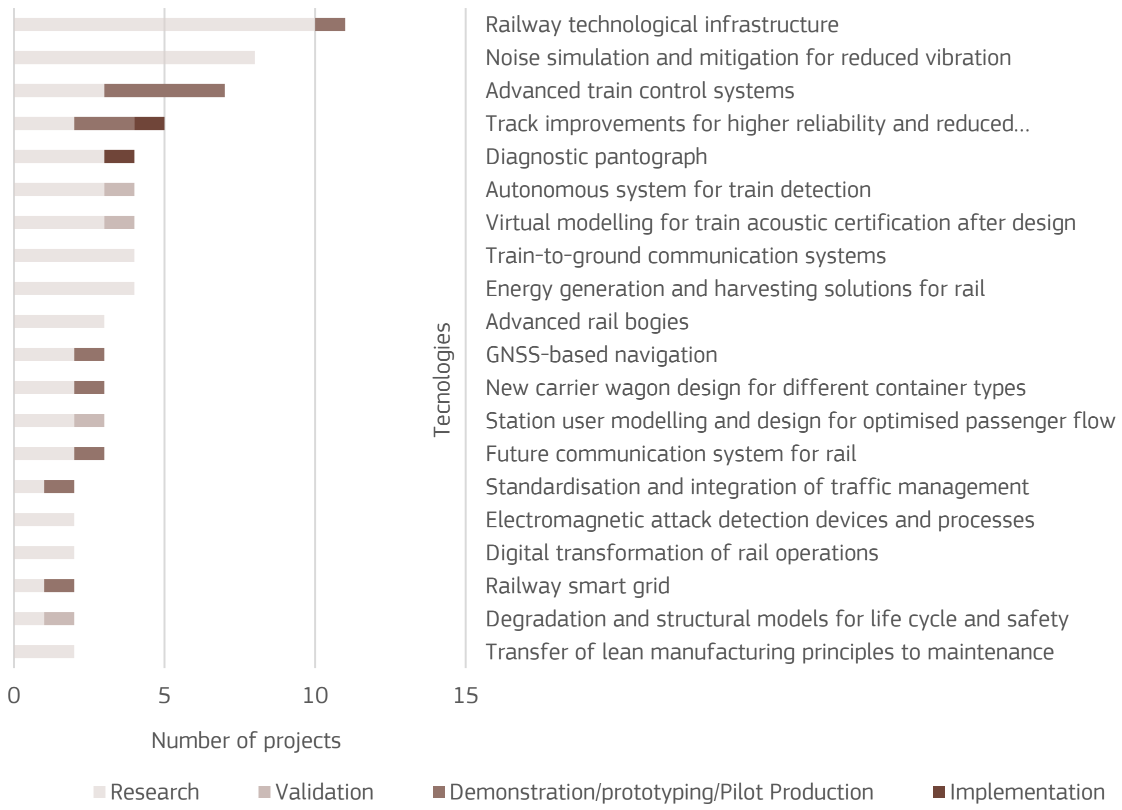
Source: TRIMIS

In addition, the technology maturity was assessed for all technologies researched within the projects. As explained in section 2, the assessment is based on the concept of TRL. In TRIMIS the nine TRLs have been consolidated into four development phases: research, validation, demonstration/prototyping/pilot production, and implementation.

[39] This diagram was created using the iTOL online tool https://itol.embl.de/ (accessed on 2 March 2021)

For selecting the top technologies, a slightly different approach is used: focus is given on most research technologies relevant only to rail. As stated in section 2.4, 86 technologies are linked to transport modes that include rail transport, while, 73 are linked exclusively to rail transport. Figure 22 presents the development phases of the identified top-20 rail technologies researched.

Figure 22. Development phases for the top-20 rail technologies in terms of number of projects that investigate them



Source: TRIMIS

Looking at the top three in terms of projects that research them, *railway technological infrastructures* is researched in 12 projects in the TRIMIS database, including the S2R IN2TRACK2, which focuses on three sub-projects related to switches and crosses, track system, and bridge and tunnel infrastructure. The *noise simulation and mitigation for reduced vibration* technology, is researched in eight projects in the TRIMIS database. These include the CARGOVIBES (Attenuation of ground-borne vibration affecting residents near freight railway lines) FP7 project, which, after establishing human response towards the existing evaluation criteria, it designed mitigation measures, assessed the effect of new and existing mitigation measures and demonstrated the effectiveness of mitigation measures through modelling and laboratory tests. Finally, *advanced train control systems* have been researched in eight projects. These include Next Generation Train Control (NGTC), an FP7 project at an initial low development phase, which analysed the commonality and differences of required functionality of the European Traffic Control System (ETCS) and Communications-based train control (CBTC) and determined the level of commonality of architecture, hardware platforms and system design that can be achieved. Other projects researching these technologies come from Shift2Rail and include X2RAIL-2, CONNECTA and CONNECTA-2. X2RAIL-2 (Enhancing railway signalling systems based on train satellite positioning, on-board safe train integrity, formal methods approach and standard interfaces, enhancing Traffic Management System functions) aims to research and develop four selected key technologies to foster innovations in the field of railway signalling and automation systems. These include fail-safe train positioning, on-board train integrity, formal methods to innovate and standardise processes and interfaces in signalling, and, traffic management evolution to improve standardisation and integration of traffic management processes. X2RAIL-2 aims at reaching TRL5/6 demonstrators. CONNECTA (Cost-efficient and reliable trains, including high-capacity trains and high-speed trains) conducted research into new technological concepts, standard specifications and architectures for train control and monitoring, with specific applications in train-to-ground communications and high safety electronic control of brakes. In particular, it aimed at contributing to the Shift2Rail's next generation of Train Control and Monitoring System (TCMS) architectures and components with wireless capabilities as well as to the next generation of electronic braking systems. The ongoing CONNECTA-2 aims to continue the activities started in CONNECTA to bring the technologies to TRL4/5 and deploying them in relevant laboratory scenarios.

The approach taken in this technology assessment is not without limitations. First, in the TRIMIS technology assessment process, the development phases refer to the initiation of the project. This was considered necessary since information on the final development phase (or TRL) are difficult to be extracted from project deliverables. In addition, ongoing projects are included in the assessment. Second, the development of the technology database has been cross-modal. In this sense, the granularity and labelling of technologies (and technology themes) become less clear when linked to a single mode. Considering the above, a more comprehensive source of information on the expected TRLs of Shift2Rail's actions and projects can be found in the annual Shift2Rail work plans[40].

Albeit the limitations, the TRIMIS exercise of identifying several technology metrics can be useful for identifying technology value chains and 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 aggregation levels.

[40] https://shift2rail.org/about-shift2rail/reference-documents/annual-work-plan-and-budget (accessed on 3 February 2021)

6 Research and Innovation assessment

This section analyses R&I projects in the rail transport field under six sub-themes, which cover the key areas of research being undertaken under this area. The analysis provides an overview of the research being performed, the key results and the subsequent implications for future research and policy development. The sub-themes, as reported in Section 5.1, are:

1. Efficient stock design and manufacturing (**stock design**)
2. Emissions and noise reduction (**emissions reduction**
3. Track and stock maintenance (**maintenance**)
4. Efficient rail operations (**operations**)
5. Infrastructure management (**Infrastructure**)
6. ICT solutions to enhance the rail travel experience (**ICT solutions**)

Table 8 provides a summary of the number of projects identified under each of these sub-themes, together with the associated total project value and the EU funding contribution. Project selection was based on projects funded by FP7 and Horizon 2020 (including those projects under Shift2Rail)

This approach identified 285 projects; some projects may be assigned to more than one sub-theme and as a result, the total of the numbers of projects in Table 8 is greater than the number obtained by summing figures from Table 4, Table 5 and Table 6.

Table 8. Rail transport research project summary table

Rail research sub-theme	Number of projects	Total project value (in € million)	Total EU contribution (in € million)
Efficient stock design and manufacturing	41	104.4	84.9
Emissions and noise reduction	37	111.5	84.3
Track and stock maintenance	36	71.3	67.7
Efficient rail operations	65	251.5	191.8
Infrastructure management	67	160.2	133.5
ICT solutions to enhance the rail travel experience	39	88.6	73.9

Source: TRIMIS

It is also possible to assess the projects by funding source, as presented in Table 9. Note that, whereas a project may address topics under multiple sub-themes (and, therefore, double counting may appear in Table 8), each project is assigned to only one funding source in Table 9.

The sub-theme analysis has focused on projects funded by the Horizon 2020 and FP7 programmes. As shown in Table 9, Horizon 2020 projects covered in the analysis receive the most significant EU funding contribution, followed by FP7 projects.

Table 9. Rail transport research by parent programme summary

Parent programme	Number of projects	Total project value (in € million)	Total EU contribution (in € million)
Horizon 2020	37	124.2	108.4
FP7	57	315.3	206.9
S2R	103	769.9	423.5
CEF	4	11.6	6.7

Source: TRIMIS

In the projects analysed in the rest of this section, reference will be made to TRLs and, particularly, the TRIMIS development phases of the projects in each sub-theme. This will provide an indication of the maturity of the technologies.

The list of projects financed under the Horizon 2020 programme, includes 18 projects from Shift2Rail launched in December 2020. Considering their very recent start date, some of these recent projects are included in the presented assessment of selected projects only under the R&I activities section. They are also included in the sub-themes tables and in Annex 1. Annex 1 includes also a Coordination and Support Action (CSA) on hyperloop (project Hypernex: Ignition of the European Hyperloop Ecosystem[41]), which does not fall under any of the six sub-themes. The project focuses on a mapping of hyperloop technologies, on technological definitions, and, on technology transfer.

6.1 Sub-theme 1 – Efficient stock design and manufacturing

This sub-theme focuses on innovations in the area of rail stock (passenger trains, freight locomotives and wagons) in terms of both design and manufacturing. Increasing efficiency can be through reducing vehicle energy consumption by lighter components, or through optimal manufacturing techniques to reduce costs and energy.

6.1.1 Overall direction of R&I

The projects under the efficient stock design and manufacturing have objectives to reduce passenger train and freight wagon weights using lightweight composite materials. Projects are in development of silicon carbide (SiC) technology for train traction systems, which can reduce the energy consumption (and therefore reduced carbon emissions) and save costs from reduced maintenance needs.

There are also projects investigating how to improve freight operation performance through improving freight logistics operations, increasing wagon load capacity, optimising loading and unloading processes and increase wagon flexibility in order to help intermodality and allow freight wagons to carry a diverse type of goods.

6.1.2 R&I activities

A total of 50 projects were assigned to this sub-theme, with a large majority funded by Shift2Rail, as shown in Table 10.

Table 10. Sub-theme 1 research by parent programme summary

Parent programme	Number of Projects	Total project value (in € million)	Total EU contribution (in € million)
H2020	5	19.5	18.6
FP7	11	38.6	25.5
S2R	34	104.2	60.2
Total	50	162.3	104.3

Source: TRIMIS

[41] hypernex.industriales.upm.es/ (accessed on 25 February 2021)

To provide a more detailed analysis, some key projects were selected to demonstrate the core areas of research undertaken in the field of efficient stock design and manufacturing. The projects have been selected based on one or more of the following criteria: available project results; recent project completion date and high project value.

- Project partners within ROLL2RAIL (2015-2017) aimed to develop key technologies in the area of rolling stock innovation. ROLL2RAIL focused on technological innovations in different subsystems of the vehicles. Individually and combined they contribute to the achievement of the desired impact at vehicle and whole railway system level with regard to capacity, reliability, efficiency, comfort and life cycle costs. The project partners investigated innovations in eight different areas such as traction, train communications, car bodyshell, running gear technologies, brakes, train interiors, noise and energy performance. Specific objectives included development of a new traction technology based on emerging electronic components and motor-wheel high-speed equipment and reduced vehicle weight to increase space available for passengers using car body solutions based on lightweight composite materials.

- The FR8RAIL (2016-2019) aimed to producing technical demonstrations of the next generation of freight bogies and freight wagons, for the competitiveness of rail freight and the feasibility of a change in modal split. The project focused in the creation of a framework and functional requirements for the development of a track friendly, low weight, low noise high speed running gear capable to run under both standard wagon bodies and freight wagons.

- The Mat4Rail (2017-2019) project focused on (i) the train weight reduction, by developing novel Fibre Reinforced Polymers (FRPs) which can replace structural metal parts of the carbody, and (ii) on increasing the capacity and passenger comfort, by means of a modular train interior. Regarding the first point, the project developed and tested FRP and joints that meet Fire, Smoke & Toxicity (FST) requirements of the railway sector. Focusing on the train interior design, the projects identified requirements based on the needs of the traveller, the operator and the train producer. The innovation potential was identified by assessing emerging technologies in the field. For the most promising concepts 3D virtual and physical prototypes were produced.

- Similarly, to Mat4Rail, the ongoing CARBODIN project (2019-2022) will develop innovative and cost-efficient solutions for manufacturing car body shells, combined with lightweight material, innovative doors and train modularity. In particular, it will research the use of composite materials for carbody shells, new lightweight composite structures for doors, and, new modular concepts for train interiors.

- The PINTA (2016-2018) project was aimed at addressing the two key topics highlighted in the first Shift2Rail Call topic S2R-CFM-IP1-01-2016 – Development of concepts towards the next generation of traction systems and management of wheel/rail adhesion, namely Traction and Adhesion Management. The Traction sub-project had objectives including increase of line capacity through weight, volume and noise savings of traction equipment, increase operational reliability, and reduced railway system lifecycle costs. For the Brakes sub-project, specific objectives included the improvement of braking degradation in poor adhesion conditions and the improvement of the overall train safety through management of the wheel/rail contact.

- The SUSTRAIL (2011-2015) project aimed to initiate a new rail era by designing novel freight vehicles that utilise lightweight materials. Secondly, the group planned to develop new track infrastructure, involving optimised track geometry plus ground stabilisation and innovative monitoring techniques. The developments targeted an improvement in rail freight efficiency and reliability while reducing maintenance frequency and costs.

- HERMES (2015-2018) was a project with objectives to incorporate innovative solutions to improve rail freight wagon load capacity. Specific objectives of the project included improving freight logistics operations, increasing wagon load capacity, optimising loading and unloading processes and increase wagon flexibility in order to help intermodality and allow freight wagons to carry a diverse type of goods.

- The RUN2RAIL (2017-2019) project was aimed at exploring technical developments for future running gear; investigating ways to design trains that are more reliable, lighter, less damaging to the track and quieter. Specific objectives included the use of novel materials and manufacturing methods in combination with intelligent suspension systems to enable non-conventional running gear concepts, and identification of efficient fabrication process for the running gear, including three-dimensional (3D) metal printing and automated tape layering of composite materials. A final objective of the project was to perform a preliminary evaluation of the related regulatory and standardisation issue of the technologies.

- Focusing on very recent projects that started during the past few months, GEARBODIES will try to facilitate the extension of overhaul periods by developing high-performance and long-lifetime components for running gear. RECET4Rail will focus on several new technologies for the train traction drive sub-system, which moves the train by means of converting energy from an electrical source to mechanical energy, including 3D printing technologies for new traction components use cases and the optimal sizing of the dynamic wireless power transfer system.

6.1.3 Achievements

Based on the research projects identified above, a number of advancements were made in the efficient stock design and manufacturing sub-theme:

- Results on the use of lightweight materials for railway carbody shells from the ROLL2RAIL project showed that the external geometry of the car body can reduce the total weight by up to 20%. Different lightweight materials were assessed for their use in structural parts of the car body and for joining different parts. Technological developments from the project focused on the development of SiC technology for train traction systems and the simulation of car body shell prototypes made of lightweight materials. Regarding the work on SiC a standard specification of new power semiconductor traction systems has been written.
- The development of lightweight FPRs within Mat4Rail, together with an optimised access door system in terms of architecture and materials, will lead to the reduction of the weight of carbody shell sections by up to 30% and a weight reduction of access door systems by 10-20%. The innovative interior design concepts could lead to an increase in the capacity by up to 30%, combining also reduced maintenance costs and reduced energy consumption due to the weight reduction, while at the same time, increasing the passenger comfort and satisfaction.
- FR8RAIL identified and evaluated several wagon design concepts, optimising for the freight capacity, the (low) weight, the maximum stiffness and improved tightness. Different running gear concepts (e.g., with double or single suspension) were considered, and the acoustic and aerodynamic characteristics of the freight wagon design, including the wheels, were further optimised.
- The results from the PINTA and PINTA2 projects included the design of a SiC traction converter for tramway applications as well as for metro applications. The main benefits found from these designs are reduced energy consumption (and therefore reduced carbon emissions) and savings from reduced maintenance needs. Two prototypes (power module, gearbox) have been developed through the projects and testing of these is planned. On the improvement of knowledge of power components for higher reliability, additional information of environmental conditions inside the electronic compartment based on existing measurements was developed. The profiles for the electrical stress of the related semiconductors were also developed through the PINTA and PINTA2 projects.
- Researchers part of the SUSTRAIL project designed, built and tested a prototype lightweight vehicle on a special track, along with upgraded infrastructure. Testing also examined economic costs and benefits. The prototype successfully met the requirements identified at the start of the project. The outcomes were then made available for implementation as part of a sustainable and efficient rail freight network. Researchers later conducted substantial dissemination work, particularly to the EC, other EU projects and interested stakeholders.
- The multifunctional smart wagon and facilities developed within the HERMES project have proved to simplify and speed up the loading and unloading operations of freight wagons, allowing for increased multimodality and reduced cycle-times. In addition, the HERMES solution proposes a logistics management similar to the truck, avoiding wagons running empty due to the high flexibility and tailor made purpose, allowing the load carriers being stored and easily transhipped, maximising its capacity for each type of good, downsizing wagon weight, and reducing the capital expenditure and the operating expenditure due to the increased productivity.
- Using knowledge of the metallurgical properties of metallic powders, in combination with expertise in the use of high-power lasers, allowed the team within the RUN2RAIL project to produce an innovative axlebox. This has the required mechanical properties of a standard axlebox, but is 30% lighter and smaller than current state-of-the-art. A concept for an innovative single-axle running gear with active

suspension and active wheelset steering has also been developed that promises significantly lower weight and lower cost due to simplified design and fewer parts. The concept will be further explored in the NEXTGEAR and PIVOT-2 projects

6.1.4 Implications for future research

Project partners within the SUSTRAIL project designed and prototyped lightweight freight vehicles which reduced energy consumption of the locomotive. Future research could explore the use of these lightweight vehicles not only in freight applications but in passenger applications as well. The research could explore the suitability of lightweight materials in passenger carriages to reduce energy consumption in passenger rail.

From the ROLL2RAIL and PINTA projects the use of silicon carbide in railway applications has reached the prototyping phase. Future research could focus on bringing the promising technology to implementation phase through demonstration of the technology. The PINTA project specifically investigated SiC use in tramway and metro applications. Future research could focus on the applications for other railway modes, such as high-speed passenger rail and freight services.

6.1.5 Implications for future policy development

Both the ROLL2RAIL and the PINTA project explored the development of silicon carbide for train traction systems which are more efficient than traditional silicon only converters. As this technology has shown benefits over the traditional materials, the standard specification for new power semiconductor traction systems should be carefully considered and perhaps developed into EU wide standards which can ensure all future use of SiC in rail applications is develop to an acceptable standard.

6.2 Sub-theme 2 – Emissions and noise reduction

This sub-theme focuses on research projects investigating the reduction of railway noise and emissions; through reduced energy consumption and reduced railway vibrations causing noise (including track interventions to reduce noise).

6.2.1 Overall direction of R&I

There is a strong focus within the research projects for mitigation of railway noise through on-board monitoring systems and predictive noise and vibration methods. The increase in noise is caused by increased vibrations due to maintenance needs in many cases. Therefore, projects are investigating localised predictive maintenance to mitigate the nose from rail.

Projects are also researching the reduction in energy consumption through energy management systems and improving vehicle efficiency.

6.2.2 R&I activities

A total of 48 projects were assigned to this sub-theme, with a large majority funded by Shift2Rail, as shown in Table 11.

Table 11. Sub-theme 2 research by parent programme summary

Parent programme	Number of Projects	Total project value (in € million)	Total EU contribution (in € million)
H2020	5	9.7	9.0
FP7	12	56.0	37.4
S2R	27	104.1	55.2
CEF	3	7.2	4.1
Total	47	111.4	84.4

Source: TRIMIS

To provide a more detailed analysis, some key projects were selected to demonstrate the core areas of research undertaken in the field of emissions and noise reduction. The projects have been selected based on one or more of the following criteria: available project results; recent project completion date and high project value.

- The Acoutrain project (2011-2014) aimed to develop procedures and calculation tools to simplify the Noise Technical Specification for Interoperability (TSI) test procedures. The main goal was to speed up the rolling stock authorisation process by introducing elements of virtual testing maintaining at the same time a certain degree of reliability and accuracy. In addition, it contributed in other areas of rail noise research: on methods for separation of infrastructure and rolling stock noise contributions, on the establishment of measurement procedures for new running conditions (such as braking and curving), and, on the development of procedures to obtain inputs for the European Noise Directive (END) [42].
- The CARGOVIBES (2011-2014) project aimed to develop and assess measures to ensure acceptable levels of vibration for residents living in the vicinity of freight railway lines in order to facilitate the extension of freight traffic on rail. In operational terms the project was aimed at developing:
    1. Criteria for the evaluation of the adverse effects. These criteria were to be formulated as extensions of current guidelines.
    2. A protocol for the assessment of the effect of mitigation measures.
    3. Three new mitigation measures: a measure for the rolling stock, one for the track and one in the propagation path. These measures were to be pilot tested and validated in service.
    4. A catalogue of mitigation measures, for use of railway community.
- The objective of the QUIET-TRACK (2013-2016) project was to provide a step change in mitigating track-based noise. Targets within the project included the integration of the low frequency noise emission and of the actual wheel rail contact conditions for more accurate predictions of the noise emitted by the track, and the development of on-board monitoring systems to make it possible to use the real roughness values and track decay rate values measured directly at the track location where maintenance action is required or where mitigating solutions have to be applied. New track solutions, including embedded track systems, were to be developed to yield a noise reduction performance of at least 6 dB(A) in comparison with the global rolling noise measured on a well-maintained standard track in the network of the participating infrastructure managers. The solutions will be applicable to tram, light rail, and metro tracks as well as to conventional tracks in across the EU.
- The main goal outlined at the start of the FINE 1 (2016-2019) project was to reduce operational costs of railways by a reduction of energy use and noise related to rail traffic. The project aimed at development of practical methods for predicting noise performance on a system level including both rolling stock, infrastructure and its environment. The overall objective of the project was to advance the state-of-the-art noise modelling and control as well as energy management methodology to promote a modal shift to rail.

[42] https://ec.europa.eu/environment/archives/noise/directive.htm html (accessed on 23 March 2021)

- The OSIRIS (2012-2015) project aimed at reducing energy consumption in urban rail systems. Project partners aimed to take a holistic approach to reducing urban rail energy consumption by examining the efficiency of vehicles, infrastructure and operation. The ultimate aim was to be able to reduce energy consumption by 10% by the year 2020. Specific objectives included the use of optimisation methodologies in order to identify efficient strategies for realising low energy consuming urban rail systems, based on the OSIRIS tool.
- The OPEUS project (2016-2019) aimed to develop a simulation methodology and a modelling tool to evaluate, improve and optimise the energy usage of rail systems. The project built on previous studies to expand and develop the simulation modelling tool (CleanER-D, MERLIN), to complete the operational requirements by enhancing previously defined urban duty cycles (OSiRIS), and, to provide a global vision of energy consumption in railways (CleanER-D, OSIRIS).
- The project DESTINATE (2016-2018) had an overall aim to develop methodologies and tools that facilitate informed decisions on cost-efficient rail noise mitigation options. This main objective is supported by specific objectives including the development of an improved methodology and algorithm for addressing the cost-effectiveness of noise mitigation and sound design, development of a novel simulation model of interior noise, based on operational transfer path measurements, and development of visualisation of noise scenarios to support the demonstration of mitigation methods' efficiency.
- Focusing on very recent projects that started during the past few months, the SILVARSTAR project, aims to develop (i) a user-friendly prediction tool for ground vibration for environmental impact studies, and (ii) a fully functional system for auralisation and visualisation based on physically correct synthesised, both interior and exterior railway noise, providing interfaces with Virtual Reality (VR) visualisation software

6.2.3 Achievements

From the research projects identified above a number of advancements were made in the emissions and noise reduction sub-theme:

- Acoutrain delivered a framework for noise virtual, including the development of dedicated tools for virtual modelling of noise TSI, and, the development and evaluation of testing and modelling procedures for the characterization of significant vehicle and track sources.
- Three viable and efficient mitigation measures to allow more freight rail traffic and fewer negative effects were designed and validated through the CARGOVIBES project. The first measure used on-board and track-based monitoring equipment to pick up excessive vibration from wagons, locomotives and track sections. The second approach reduced ground-borne vibrations by replacing wooden or concrete sleepers with ladder track or similar track structures. Soil barriers provided the final measure, which can be applied when track-based solutions are not feasible. The soil barrier approach was suitable for improving an existing situation with minimum disturbance to the railway.
- Results from the QUICK-TRACK project showed a decrease in rail noise emissions by at least 6 dB(A) compared to current global railway averages; therefore, attaining the initial objective set out at the start of the project. This was achieved through the integration of low-frequency noise emission and actual wheel rail contact conditions for more accurate predictions of the noise emitted by tracks. Project partners also developed on-board monitoring systems based on noise measurements and location sensors that continuously monitor rail roughness values, track decay rate values and wear. These systems help to identify track locations where maintenance is needed or where noise mitigating solutions have to be applied.
- Through the FINE 1 project an innovative technology for auralisation and visualisation of noise scenarios was developed with the complementary project DESTINATE. This technology gives the possibility of listening and experiencing visually the noise of trains passing on a certain track at the early design phase. This system was demonstrated at the InnoTrans 2018 conference. For the energy part of the project, an energy simulation tool was developed by the complementary project OPEUS and is now used by the FINE 1 project. Data is collected from technology developments in different parts of Shift2Rail and new energy consumption reductions are calculated quantifying the overall progress. A proposal for eco-labelling was also developed.

- Project partners within the OSIRIS project tested three technological innovations for engines, all of which showed improved energy performance. The project team also created a list of operational changes that require no technology to implement, which holds promise for further energy savings. Finally, OSIRIS incorporated all of their research into decision support software for rail engineers and others involved in urban rail management. Useful project outcomes include common Key Performance Indicators (KPIs) and technical recommendations. These will help rail networks reach energy efficiency targets and lead to more sustainable public rail systems in Europe.
- OPEUS developed an energy simulation model that uses case studies to assess the energy usage implications of introducing technological innovation into rolling stock, while in general, it contributed to the development of a holistic approach to energy efficiency in rail. The developed tool can support decision-makers in selecting technologies, and thus, improve the energy performance of rail vehicles. For example, one assessment studied the effect of reducing the overall weight and making performance improvements to various components on specific high-speed rail services, concluding that such changes result in a 2% decrease in traction energy at the wheel level, which leads to a total net energy reduction of 5.4% at the energy source.
- Within the DESTINATE project, the applicability of Cost-benefit analysis (CBA) to support decisions on rail noise mitigation was investigated for five fields of application. The method was demonstrated to work well in assessing the cost-efficiency of different mitigation measures for exterior rail noise. Operational transfer path analysis (OTPA) was used to identify and rank main railway noise sources for the TramLink prototype of Stadler Rail Valencia. These were measured for real operation conditions on the Valencia network. Based on these measurements a model was built with the capability to predict design changes. To validate the model, a second measurement campaign was carried out in Gmunden (Austria) on a TramLink. It was shown that the model is capable of predicting certain design changes for trains of the same class.

6.2.4 Implications for future research

The FINE 1 project proposed an idea for energy-labelling for rail rolling stock. This could be explored further, as eco-labels can encourage end-users to select more efficient and environmentally friendly systems. This is because more eco-friendly systems are typically less energy consuming, and therefore less expensive to the end-user. Perhaps the use of a lifecycle cost label in addition to the eco-label could encourage users further to select efficient systems as they could see cost benefits along with emission savings.

6.2.5 Implications for future policy development

Limits for pass-by railway noise within the EU currently range between 79 and 99 decibels, depending on maximum speed and type of rolling stock subsystem. As results from projects such as QUICK-TRACK have shown a reduction in rail noise is possible, perhaps new policy should reflect the improvements in technology and encourage railway operators to reduce noise further than current EU limits. This could be implemented through stricter limits on pass-by noise for rail subsystems.

The OSIRIS project tested technical innovations for engines, all of which showed an improvement in energy performance. The target of the project was to reduce energy consumption in 2020 by 10% compared to the start of the project (2012). Whilst these technologies are beneficial in the short term, future policy should consider if these small benefits to engine efficiency are still worth pursuing, or if more drastic measures are needed for net-zero targets across Europe resulting in diesel traction required to be phased out altogether.

6.3 Sub-theme 3 – Track and stock maintenance

This sub-theme focuses on technologies to predict maintenance needs of both rolling stock and the railway tracks, as well as techniques for monitoring the condition of each in real-time.

6.3.1 Overall direction of R&I

Projects are investigating the use of predictive monitoring for overhead line faults, track inspection and axle bearing monitoring and diagnosis. The research is focused on more predictive and preventative measures rather than the actual fixed of faults. These technologies are based on sensors, lasers and even cloud-based systems.

The technologies researched in the below sections are largely at advanced stages of the development phase.

6.3.2 R&I activities

A total of 40 projects were assigned to this sub-theme, as shown in Table 12.

Table 12. Sub-theme 3 research by parent programme summary

Parent programme	Number of Projects	Total project value (in € million)	Total EU contribution (in € million)
H2020	13	23.9	19.9
FP7	11	32.6	21.7
S2R	16	57.9	30.2
Total	40	71.3	67.7

Source: TRIMIS

To provide a more detailed analysis, some key projects were selected to demonstrate the core areas of research undertaken in the field of track and stock maintenance. The projects have been selected based on one or more of the following criteria: available project results; recent project completion date and high project value.

- The IN2SMART (2016-2019) contributed to railway Intelligent Asset Management Systems (IAMS), and in particular on predictive maintenance, focusing on three layers: (i) measuring and monitoring systems to collect, process and aggregate railway asset status data, (ii) data management, data mining and data analytics procedures to process data from the field, (iii) decision making, maintenance strategies and execution procedures for the development of a generic framework. The follow-up IN2SMART-2 (2019-2022) project is aimed at implementing specific demonstrators. The project will focus on a multi-action plan to deliver innovative asset management, by creating new and optimised strategies, processes, tools, products and systems, to implement risk-based, prescriptive and holistic asset management.
- The high-level aim of the project AUTOMAIN (2011-2014) was to make the movement of freight by rail more reliable, available, maintainable and safe; with a reduction in downtime of the rail system by 40% targeted through the project. Specific objectives to achieve this goal included the

development of novel track inspection approaches for freight routes with a scope on in train measuring and self-inspection technology, and developing a new maintenance planning and scheduling tool that is able to optimise the maintenance activities, taking account of the benefits brought about by other improvements in this project.

- The tCat (2017-2019) targeted improvements to an already existing technology, which can automatically and accurately detect overhead line faults. The upgrades to the technology through the tCat project were to adapt a former prototype to respond to market requirements, and to test and demonstrate the updated prototype through four pilots throughout the most representative markets (the UK, Germany, Spain and the US).
- Real-time 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 targeted at delivering major benefits through cost reductions of rail track maintenance as well as improved train safety and operational reliability.
- AMINSA has developed DTD SYSTEM (DTD SYSTEM 2, 2017-2019), an innovative system capable of detecting with high precision wheel defects at their onset, using this information to design a predictive maintenance plan. DTD SYSTEM´s added value compared to competing systems is:
  1. Higher accuracy in identifying wheel defects,
  2. Reduction in track maintenance needs,
  3. Easier and personalised service attending to each user's needs,
  4. Reduction in wheel inspection and maintenance and renewal costs.

The successful execution of Phase 1 has led to the definition of a business model to deploy DTD SYSTEM as a service and reach the EU market, establishing strategic alliances with stakeholders, users as well as commercial suppliers. The overall objective in Phase 2 was to implement advanced demonstration units of DTD SYSTEM in the most complex and demanding conditions, as well as develop the tools needed to introduce DTD SYSTEM in the railway market.

- The MAXBE (2012-2015) project had a strategic objective to provide validated and demonstrated concepts, strategies and guidelines for the interoperable axle bearing monitoring and diagnosis that support the railway operators and managers dealing with axle bearing defects. The consortium consisted of one axle bearing manufacturer, a market leader in the field, and three operators and railway managers as end-users to ensure interoperability of the technology. The MAXBE project was expected to improve for the reliability, availability, maintainability and safety (RAMS) of rolling stock and infrastructure, focused on the axle bearings.
- Focusing on very recent projects that started during the past few months, among the technologies the TAURO project aims to analyse and finally propose for the future European automated and autonomous rail transport, is one on the automatic status monitoring and diagnostic for autonomous trains. The DAYDREAMS project will develop prescriptive railway IAMS (i) advancing in maintenance approach towards prescriptive asset management, (ii) improving the decision-making process by developing multi-objective decision optimisation approaches, and (iii) reinforcing the role of the person-in-the-loop by designing and developing advanced context-driven Human Machine Interfaces (HMIs) to allow context- and risk-aware multiple-options decision-making processes. Within the IN2ZONE project, which focuses on solutions for track transition zones (i.e., sections of track where the track stiffness undergoes a drastic change) an advanced resilience-based monitoring solution for transition zones will be developed, which will fuse data from multiple track, vehicle and satellite sensors, using edge computing and AI. The STREAM project will focus on robotics applied to safe railway construction, inspection and maintenance, and will highlight the role of digitalized maintenance process integration in the design of new, more collaborative tools and working methods. The FR8RAIL IV project will focus among other activities on defining CBM use cases for rail freight, in order to create an advanced monitoring solution for different rolling stock types across Europe.

6.3.3 Achievements

From the research projects identified above a number of advancements were made in the track and stock maintenance sub-theme:

- The IN2SMART project defined a set of 11 use cases, illustrating real-life railway IAMS issues. It also presented a consolidated list of requirements and specifications for data processing, including contributions to safety analysis within the maintenance and infrastructure asset management processes.
- Through the AUTOMAIN project a lean manufacturing concept (meaning to reduce production waste) was applied to key track maintenance processes, including tamping, grinding, and switches and crossings (S&C) maintenance. Initial comparison of best practices of several European rail agencies highlighted potential technologies that could reduce maintenance times. A second area of focus was inspection technologies. The project concluded that continuous, daily track monitoring was possible using in-service trains running at normal speeds. Project partners developed a laser-based trolley for assessing S&C, and the associated algorithms. The project's switch inspection device will also be able to monitor tack geometry. The prototype was shown to be able to assess approximately 130 switches per night, compared with five per day using traditional methods. The new method does not disrupt rail traffic and has no safety concerns.
- Upgrades to the tCat technology were achieved and included a significant weight reduction and ease of use of the technology, as well as the introduction of new Light Detection and Ranging (LiDAR) sensors to increase the speed of registration and accuracy of measurements. The four pilot tests were successfully executed and resulted in minor changes required to the technology. As a result of this project the partners expect three market-ready models of the tCat (tCat-1000, tCat-1435, tCat-1668) that have been demonstrated in real operational conditions in target markets involving early adopters in the UK, Germany, Spain and the US.
- 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, and 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 maintenance technology developed by AMINSA was improve through the DTD SYSTEM 2 project. The hardware and communication units were upgraded, including the integration of a cloud-based computing platform to enhance the data transfer allowing for optimal track and wheel maintenance. The product has also achieved certification and European Conformity ('CE') mark under European and worldwide regulations.
- Based on data provided from the operators within the MAXBE project, it has been established that the maintenance cycle is kilometre driven. Deterioration of the structural integrity of axle bearings can be detected using temperature, vibration and low and high-frequency acoustic emission measurements using sensors installed either on each axle bearing or wayside. Two on-board monitoring systems composed by temperature sensors, accelerometers and acoustic emission were demonstrated as prototypes within the project. The monitoring systems developed within this project have an impact in improving the reliability of rolling stock and in increasing the cost-efficiency of maintenance activities based on condition-based maintenance rather than corrective.

6.3.4 Implications for future research

Many of the research projects under the track and stock maintenance sub-theme are already well developed, reaching implementation phases. The track inspection technologies in the AUTOMAIN and WARNTRACK projects could be consolidated with an aim to create a combine track inspection system which pulls together components from each project into one system. Also, based on the results obtained in IN2SMART, the IN2SMART-2 project aims to implement specific demonstrators.

Cloud-based maintenance systems, such as those developed in the AMINSA project, are also being explored for passenger vehicle applications. Learnings could be taken from passenger cloud maintenance systems and applied to rail applications, and vice versa, through future research. This would also help with the interoperability between rail and road cloud-based maintenance systems.

6.3.5 Implications for future policy development

Project results from the AUTOMAIN track maintenance project found that using the new technology more switches can be assessed compared to traditional methods by a factor of 26, whilst not disrupting rail traffic. Switch failures cost UK railway infrastructure manager Network Rail more than £120 million a year and account for more than 3 800 000 minutes (63 300 hours) of delays. By assessing a greater number of switches per day, this number could be reduced and so the results of the AUTOMAIN project can be beneficial to the railway network. Future policy could encourage the use of this new technology, which has the potential to reduce thousands of hours of rail delays saving millions of Euros in the process.

The AMINSA project integrated a cloud-based system for maintenance of railway track and wheels. As with other connected services, the correct data protection and cyber security should be in place to ensure that the data is stored and transferred in a safe and secure way. This could be enhanced through policy measures specifically targeted at railway cloud-based maintenance systems.

6.4 Sub-theme 4 – Efficient rail operations

This sub-theme focuses on improving the efficiency of the railway through traffic management systems, automation and control systems.

6.4.1 Overall direction of R&I

There is substantial research ongoing into the ERTMS along with the sub-component ETCS, which aim to improve railway efficiency through automation and optimal signalling.

There are also projects researching optimal rail freight activities through track obstacle detection and real-time yard management systems for optimal loading and unloading of cargo.

6.4.2 R&I activities

A total of 86 projects were assigned to this sub-theme, with a large majority funded by Shift2Rail, as shown in Table 13.

Table 13. Sub-theme 4 research by parent programme summary

Parent programme	Number of Projects	Total project value (in € million)	Total EU contribution (in € million)
H2020	7	20.3	16.0
FP7	17	78.1	49.2
S2R	60	329.8	176.6
CEF	1	2.7	1.8
Total	85	430.9	243.6

Source: TRIMIS

To provide a more detailed analysis, some key projects were selected to demonstrate the core areas of research undertaken in the field of efficient rail operations. The projects have been selected based on one or more of the following criteria: available project results; recent project completion date and high project value.

- The X2RAIL-1 (2016-2019) project was part of the Shift2Rail Innovation Programme 2 (IP2, Advanced Traffic management & Control Systems). The project partners within this project aimed to research and develop six key technologies in the field of railway signalling and automation systems. Specific objectives included adapting radio communication systems to allow for more advanced rail automation systems, to improve train punctuality through more extensive use of automatic train operation systems, to ensure the backward compatibility of ERTMS/ETCS technologies, and to ensure security among all connected signalling and control systems by developing new cyber security systems dedicated to railways.
- X2RAIL-2 (2017-2020) was a follow-on project from X2RAIL-1 and under the same IP2 from Shift2Rail. X2RAIL-2 focused on four key technologies which consisted of fail-safe train positioning based on multi-sensor concept utilising Global Navigation Satellite System (GNSS), on-board train integrity to allow the application of new signalling train separation concepts, standardisation of signalling project phases, and improve standardisation and integration of traffic management processes. The X2RAIL-2 project aimed to reach demonstrators of each key technology to TRL5/6.
- Project partners within the IN2RAIL (2015-2018) project aimed to set the foundations for a resilient, consistent, cost-efficient and high capacity European railway network by exploring innovative technologies. Research into new power systems characterised by reduced losses and capable of balancing energy demands, along with innovative energy management systems enabling accurate and precise estimates of energy flows was to be performed. Intelligent mobility management was also a key area of research within the project; investigating automated, interoperable and inter-connected advanced traffic management systems; scalable and upgradable systems, utilising standardised products and interfaces, enabling easy migration from legacy systems.
- The FR8RAIL (2016-2019) project focused on the development of functional requirements for sustainable and attractive European rail freight. The objectives were to achieve a 10% reduction in the cost of freight transport measured by tonnes per km, a 20% reduction in the time variations during dwelling, and at the same time, to increase the attractiveness of logistic chains. In order to achieve these goals, the project developed a number of focused areas within freight rail (e.g., business analytics, KPIs, condition based and predictive maintenance, telematics and electrification, running gear, automatic coupling). The follow up ongoing projects FR8RAIL II (2018-2021), FR8RAIL III (2019-2022), and, FR8RAIL IV (2020-2023), are more focused on the digitalization and automation of freight rail, the smart data-based assets and efficient rail freight operation, and, the use-centric rail freight innovation for SERA.
- The SMART-RAIL (2016-2019) project had a main objective to increase the effectiveness and capacity of rail freight through the contribution to automation of railway cargo haul on European railways. This was to be achieved through the development of a prototype of an autonomous obstacle detection system, and a real-time marshalling yard management system. The obstacle detection system was to combine thermal cameras and laser scanners to provide up to 1 000m of obstacle detection on the rail tracks. The yard management system was to provide optimisation of available resources and planning of marshalling operations in order to decrease overall transport time and costs associated with cargo handling.
- The EATS (2012-2016) project set out to progress laboratory testing of ETCS on-board equipment. Overall, the aim was to improve the current testing laboratory and accelerate the testing process, leading to more efficient testing tools. Specifically, a model was to be developed of the on-board ERTMS system, which would lead to reductions in certification process time and cost through reduced laboratory and field-testing requirements. EATS also proposed a novel positioning system based on the combination of different techniques proved useful for other industrial sectors and exploit unique features of the railway and the train.
- The 4SECURAIL (2019-2021) project supports the implementation of a Computer Security Incident Response Team (CSIRT) for the European railway sector, including testing and updating the CSIRT collaborative environment. A model has been developed (CHIRP4Rail - Collaborative tHreat Intelligence Platform for Rail) which establishes actors, flows and tools within the cybersecurity concept, and defines both an organisational model (roles and functions for the actors involved,

management structure and detailed dataflows) and a technical model focusing on data standards and railway taxonomies.

- Focusing on very recent projects that started during the past few months, the X2Rail-5 project aims to bring to conclusion the research and development of some key technologies of railway signalling, automation, telecommunication, testing methodologies and Cyber-Security, bringing to higher TRL technologies developed the earlier X2Rail-1, X2Rail-2, X2Rail-3 and X2Rail-4 projects. The aim of the PERFORMINGRAIL project is to define through proper modelling and optimal traffic management, a moving block railway signalling using advanced train positioning approaches that mitigates potential hazards. It will help to bring the developments as close as possible to the market but also support the regulatory framework update. The FR8RAIL IV project, will focus among other activities on developing at high TRL automated train operation (ATO) concepts for freight, which will help to reduce system costs by means of optimal energy-efficient, low-wear, resource-efficient and flexible operations.

6.4.3 Achievements

From the research projects identified above a number of advancements were made in the efficient rail operations sub-theme:

- The automatic train operation system work package from the X2RAIL-1 project has completed the Grade of Automation (GoA) specification and is in the process of developing prototypes, which are compliant with the specifications. In terms of the cyber-security work package, an analysis of most of the subset of the IEC 62443 was done, a mitigated risk assessment of railway specific zones was performed and a proof of concept of protection profiles was achieved.
- In February 2021, the 4SECURAIL project has completed mid-term objectives towards tightening cyber security and improving signalling systems across European railways[43]. This includes designing a European railway CSIRT to improve cross-European cyber security in the rail industry, and a first version of the formal methods demonstrator to improve signalling system security. The latter will be integrated with a cost-benefit analysis for application in the railway signalling industry.
- With regard to the Traffic Management System (TMS) research within the X2RAIL-2 project, progress was made on system requirement specifications, detailed descriptions of use-cases representing advanced TMS principles and prototypes. The project also made progress above current state-of-the-art in in train positioning. Train position is one of the safety integrity level (SIL) 4 functions of the ERTMS system. Up to now, none have used the GNSS, IMU, digital map and radio localisation technologies for guaranteeing this SIL 4 function in the ERTMS standard and interoperable constituents. The on-board train integrity function and its development in accordance with the different installation needs were not addressed before in other Research and Development (R&D) projects. A cost-effective solution is the main target for supporting the application of ERTMS Level 3 functions.
- Each of the work packages within the IN2RAIL project have developed beyond the current state-of-the-art. Specifications for a fully automated TMS were established to enable integration with improved maintenance. Modelling tools were developed for intelligent alternating current (AC) power supply systems, which will enable lower energy usage and reduced energy losses through the power supply systems. A number of novel formation treatments has been investigated with respect to improving the track support structure under the optimised track system work package.
- FR8RAIL delivered detailed specification of train's wireless backbone infrastructure, including system and subsystem components and their external interfaces, and, requirement analysis and technologies evaluation. From the performed analysis of the use cases and the operational analysis, a high level architecture of the wireless backbone infrastructure system has been achieved. The project also delivered the specification of the data model for application interface of cargo and wagon monitoring system, and, technical requirements and benefit cost analysis for automatic couplers.
- Several field tests of the SMART-RAIL obstacle detection systems were conducted on rail track sites in Germany and Serbia, achieving TRL4-5. Current state-of-the-art on-board obstacle detection

[43] https://www.railjournal.com/technology/shift2rail-cybersecurity-project-achieves-mid-term-objectives (accessed on 27 March 2020)

systems for rail reach around 100m; the SMART-RAIL technology can detect obstacles beyond 200m and up to 1 000m in some cases. In terms of the real-time yard management system, a platform that was chosen allows integration to existing Information Technology platforms on marshalling yards. A concept solution of the system was developed as well as database structure of the system. Software development for real time decision support system has started based on achieved results in other areas of the project. So far, the development of the yard management system has reached TRL4.

- The EATS project resulted in the development of equipment leading to more realistic testing of ETCS components, whilst reducing certification time and cost and increasing safety and availability. It will also push in the introduction of new satellite-based positioning systems. Before integrating the smart train positioning system (STPS) into the ETCS on-board equipment, researchers defined requirements for the STPS and developed tools for its testing. The STPS is based on satellite positioning and wireless technologies to overcome current limitations in migrating to ETCS level 3.

6.4.4 Implications for future research

The STPS technology proposed in the EATS project has the potential to advance the ETCS towards level 3 through overcoming some of the key limitations in satellite positioning. The project partners defined requirements for the STPS; future research could investigate the further development and testing of this potential technology to enhance and accelerate the transition from ETCS level 2 to level 3.

The results from the SMART-RAIL project included an obstacle detection system and real-time yard management system developed to TRL4/5. Further research into the possible prototyping and demonstration of the real-time yard management system could be conducted to quantify the benefits of the system in terms of efficiency gains.

6.4.5 Implications for future policy development

There is a large focus on ERTMS within the research, in which ETCS is the signalling and control component. X2RAIL-2 and IN2RAIL investigated ERTMS systems, whilst EATS specifically developed the ETCS components. With the large amount of research undertaken in this area, future policy could help to facilitate the roll-out of the technology, when available, across the MSs.

The results from the SMART-RAIL obstacle detection system could be considered in future ERTMS specifications, as obstacles on the railways can cause significant delays as well as accidents.

6.5 Sub-theme 5 – Infrastructure management

This sub-theme focuses on optimal management of railway infrastructure, which includes electrical infrastructure (overhead lines), level crossing safety and protection from potential threats.

6.5.1 Overall direction of R&I

There is a focus within the research projects around the management of the electrical infrastructure, with a particular emphasis on the use of the infrastructure for charging of electric vehicles and the management of the overall energy supply and resources for reduced energy consumption.

Research projects are also investigating how to improve the overall safety of the railway, from level crossing accidents being avoided to protection from electromagnetic attacks on the railway.

6.5.2 R&I activities

A total of 77 projects were assigned to this sub-theme, with a large majority funded by Shift2Rail, as shown in Table 14.

Table 14. Sub-theme 5 research by parent programme summary

Parent programme	Number of Projects	Total project value (in € million)	Total EU contribution (in € million)
H2020	13	28.0	24.2
FP7	17	84.5	54.5
S2R	46	113.4	65.2
CEF	1	1.7	0.8
Total	77	227.7	144.8

Source: TRIMIS

To provide a more detailed analysis, some key projects were selected to demonstrate the core areas of research undertaken in the field of infrastructure management. The projects have been selected based on one or more of the following criteria: available project results; recent project completion date and high project value.

– The project MERLIN (2012-2015) had a main aim to investigate and demonstrate the viability of an integrated management system to achieve a more sustainable and optimised energy usage in European electric mainline railway systems. The project was also to provide an integrated optimisation approach that includes multiple elements, dynamic forecasting supply-demand scenarios and cost considerations to support operational decisions leading to a cost-effective intelligent management of energy and resources. This was to be achieved through targets such as improved design of existing and new railway distribution networks and electrical systems as well as their interfaces with the public grid and considering network interconnections and understanding of the cross-dependency between these different technological solutions to define optimum combinations for optimised energy usage.

– Project partners within the ELIPTIC (2015-2018) project aimed to develop new use concepts and business cases for the use of existing electric public transport systems - e.g. light rail, metro, tram and trolleybus – as a charging infrastructure in a multimodal mobility context. The project had a strong focus on end users, consisting of three thematic pillars:

  - safe integration of e-buses into existing electric public transport infrastructure;
  - upgrading electric public transport systems (efficiency);
  - multi-purpose use of electric public transport infrastructure.

Whilst not fully focused on rail only, ELIPTIC did consider the impacts of electromobility on the existing electrical infrastructure for light rail and trams within urban areas.

– The NeTIRail-INFRA (2015-2018) project worked to identify and develop railway infrastructure and monitoring technology for Europe's lesser-used lines. The project's main objectives were to understand which technologies are to be used for different types of railway lines. The types of lines used in the project included freight-dominated routes, busy commuter lines and also lesser-used, under-utilised passenger lines. The work was to address growing demand for already busy services, and future growth of underutilised lines, with technical solutions for track, power supply and support of new smart services. Technical developments were focused on modular infrastructure, i.e. standard designs with multiple application in different locations, thereby reducing planning cycles, enabling a lean design process for new installation and retro fit.

- SAFER-LC (2017-2020) had objectives to improve safety and minimise risk by developing a fully integrated cross-modal set of innovative solutions and tools for the proactive management and design of level-crossing infrastructure. The project was focused on technical solutions, such as smart detection services and advanced infrastructure-to-vehicle communication systems and on human processes to adapt infrastructure design to end-users and to enhance coordination and cooperation between different stakeholders from different transportation modes. A series of pilot tests across Europe was to be rolled out to demonstrate how these new technological and non-technological solutions can be integrated, validate their feasibility and evaluate their performance.
- The SECRET (2012-2015) project investigated the impact of electromagnetic (EM) attacks on European rail networks. Comprised of an 11-member consortium, the project's objectives include threat assessment, technical protection and policy recommendations. The project considered how to proceed with a risk analysis of rail network technologies and threat assessment. The objectives of SECRET included the identification of vulnerability points and scenarios for potential EM attacks on the railway, and to develop resilient architecture to react to such attacks.
- The IN2STEMPO (2017-2022) project aims to reduce rail life-cycle costs, and, improve rail capacity and performance, making use of recent technologies, whilst ensuring an optimal customer experience. The project objectives are developed along three research areas: future stations, power supply, and, energy management. The latter focuses on railway system smart metering, by developing three use cases, for which all technological components needed for their implementation will be further developed.
- The SMART2 (2019-2022) project aims to research and develop autonomous obstacle detection systems for rail, i.e., trackside, airborne obstacle detection (OD) and track intrusion detection (TID) systems. These systems will enable an increased detection of areas in presence of elements blocking the train's view on the rail tracks (e.g., behind a curve or in tunnels), and will be integrated through interfaces to a central decision support system (DSS). After assessing this input, DSS will suggest possible actions for the train control. Additional novel OD and TID modules could be integrated in the future.
- Focusing on very recent projects that started during the past few months, the IN2ZONE project will design and test a prototype next generation track transition zone solution, which will include the design of new automatic irregularity correcting sleepers, formed from synthetic material, with optimised geometry and stiffness for transition zones. The IN2TRACK3 project, will develop physical as well as digital technology and methodology demonstrators for the track, S&C, bridge and tunnel assets, and, demonstrate a number of innovative solutions based upon the two previous IN2TRACK and IN2TRACK2 projects,

6.5.3 Achievements

From the research projects identified above a number of advancements were made in the infrastructure management sub-theme:

- Five case studies in four European countries helped evaluate various aspects of improved energy management though the MERLIN project. As there are currently no applicable standards for an integrated railway energy management system, project partners evaluated the standardisation and calibration of energy meters and information exchange protocols between components from on-board energy meters to smart grid components. Outcomes of the project included two technical recommendation proposals. The first covers business, function and component layer, and the second covers communication and information layers. Overall, MERLIN developed the components and management tools necessary for efficient energy resource management on European electric railways. The expected standardisation will make an important contribution to future development, implementation and effectiveness.
- ELIPTIC partners developed a dedicated methodology to assess the main technical, social, environmental and economic impacts of the ELIPTIC use cases. The studies from Warsaw and Leipzig focused on the connection to the tram system and related legal, technological and organizational issues. The use case partner TfL analysed the potential of using power from the London Underground

network to charge electric vehicles with no adverse effects on underground train operations and prepared a demonstration for showing that power from the London Underground grid can support regular charging of electric vehicles.

- NeTIRail-INFRA evaluated the stability of a simple trolley wire system for mainline use. Although it is more common in tramways, the trolley wire system was shown to be stable for vehicle speeds of up to 100 km/h. This potentially makes it suitable for some of the lesser-used commuter lines studied in this project. Project partners also developed and demonstrated very low-cost, self-powered monitoring equipment for electromechanical interlocking systems still used for lower-density lines. The solution allows transmission, logging and central monitoring of certain aspects of these systems' status. Partners have developed a web-based decision-support tool that encompasses all project learnings and allows users to implement cost-benefit evaluations and societal analysis.
- The final outcome of the SAFER-LC was a toolbox of 48 different solutions, made freely available online to policymakers, road and rail infrastructure managers, and civil groups. The toolbox offers the best solutions that can be targeted at different types of level crossing and each is linked to studies showing the evidence to support it. These tools can be as simple as speed bumps before a crossing, paint or optical effects that slow drivers. Adding smart sensors to passive crossings, for example, could not only warn approaching cars when a train is due but also warn train drivers if a vehicle is detected on the tracks. The SAFER-LC project ran a trial in Thessaloniki, Greece, where a fleet of 100 taxis were equipped with such sensors, the results of which are 'promising'.
- The SECRET project identified the three most probable classes of EM attack on the railway. Two were possible but technically difficult, leaving the most credible threat as the jamming of information transmitted between system components. Publicly detailing such threats makes implementing them easier; therefore, a 'use case' lacking sensitive information has been defined to test various solutions. Laboratory testing characterised the signals produced by jamming devices and assessed the vulnerability of receiver equipment. Similar measurements were performed along the tracks, as well as inside train carriages and stations. Data was collected showing the effect of separated two-part EM attack devices. The team has proposed a protection solution that combines robust communications architecture with an attack management sub-system. Testing will commence in a future phase of the project.
- The still ongoing SMART2 project identified and analysed freight specific use cases for the further development of OD and TID systems. The next step is the analysis of the requirements and the definition of specifications for the OD and TID system to be developed for the project.

6.5.4 Implications for future research

The railway energy management system developed within the MERLIN project could be developed further using the results of the ELIPTIC project to investigate an energy management system for the railway when it is being utilised to charge electric vehicles. This would ensure that the mass transition to electric vehicles would not only be supported by the existing railway infrastructure, but the railway infrastructure will still have sufficient capacity for its own needs.

Of the three most probable cases of EM attack on the railway system identified within the SECRET project, only one was deemed feasible enough to be investigated further. Future research could investigate the two possible but technically difficult probable classes of EM attacks. This is because whilst technically difficult currently, there is still the risk of these types of attack occurring in future when technology develops further.

6.5.5 Implications for future policy development

As electrification of multiple transport modes increases across Europe, there will be an increasing need for integrated railway energy management systems to help ensure electrical capacity is available for trains and locomotives. The expected standardisation of railway energy management systems developed in the MERLIN project could be implemented across Europe to ensure that all electrical railway infrastructure is well managed and has sufficient capacity to fulfil the needs of the railway.

Level crossings are involved in just 1% of road deaths, but 30% of deaths on the railway. Smart sensors, along with many other measures, were investigated in the SAFER-LC project to warn both approaching cars as well as train drivers of potential dangers at level crossings. As the proportion of deaths on the railway is so large from level crossings, future policy could ensure that the measures developed within the SAFER-LC project are implemented as much as possible to improve the overall safety of the railway.

6.6 Sub-theme 6 – ICT solutions to enhance the rail travel experience

This sub-theme focuses on services to improve the passenger experience, including smart-ticketing systems spanning multiple transport modes and considering passengers with restricted mobility.

6.6.1 Overall direction of R&I

A strong theme throughout the research presented below is the development and use of co-modal ticketing systems, supporting intermodal journeys and Mobility as a Service (MaaS), which can provide the users with an optimised journey plan based on their preferences. This also includes the options for mid-route stops; resulting in suggestions of local leisure activities such as restaurants. This is not only confined to passenger travel, but also the optimal flow of goods through freight services.

There are also research projects which consider how to optimise the rail travel experience for passengers with restricted mobility, including baggage handling and passenger flow through stations.

6.6.2 R&I activities

A total of 42 projects were assigned to this sub-theme, with a large majority funded by Shift2Rail, as shown in Table 15.

Table 15. Sub-theme 6 research by parent programme summary

Parent programme	Number of Projects	Total project value (in € million)	Total EU contribution (in € million)
H2020	9	22.6	20.6
FP7	8	25.6	18.6
S2R	25	60.3	35.9
Total	42	108.5	75.1

Source: TRIMIS

To provide a more detailed analysis, some key projects were selected to demonstrate the core areas of research undertaken in the field of ICT solutions to enhance the rail travel experience. The projects have been selected based on one or more of the following criteria: available project results; recent project completion date and high project value.

- The main goal of the Co-Active (2016-2019) project was to improve the interoperability between different booking & ticketing systems at regional or even national scale. This was to be achieved through three objectives:
    1. Provide a smart, fast & easy door-to-door travel shopping solution, allowing multimodal journey planning & shopping of itineraries as well as associated ancillary services,

2. Provide a smart, fast & easy door-to-door booking & ticketing solution, allowing multimodal travel booking, payment & re-accommodation (cancellation or replacement),

3. Simplifying the Business to Business (B2B) & Business to Consumer (B2C) contractual management in order to ease the understanding of each actor's rights/responsibilities as well as the traveller guaranties, especially in case of disruption needing a prompt re-accommodation.

– Project partners within the My-TRAC (2017-2020) project aimed to develop a novel transport services platform for the rail sector, designed for public and private transport users and operators. It aims to provide an improved passenger experience by developing and applying advanced behavioural and transport analytics and AI algorithms to meaningful data gathered from diverse public transport and open data sources. Specific objectives of the project included the development of a smart human machine interface to provide users with viable access to the information, depending on their individual needs, specifically addressing impairments of stable or transitory nature (e.g. visual impairment, technological illiteracy) through My-TRAC Travel Companion.

– FAIR Stations (2017-2019) was a project, which had an overall objective to develop solutions for improved users flow within the station and at platform train interface (PTI). The project was to investigate user needs, user flow through stations, station design algorithms to optimise passenger flow, and engineering design of a train and/or platform-based mechanism to aid passengers with restricted mobility using sensors and detection systems. As part of the demonstration, experimental and in-situ tests were to be conducted.

– ATTRACkTIVE (2016-2018) aimed at implementing two innovative technologies to enhance the rail user experience, the Trip Tracker and the Travel Companion. The Trip Tracker provides the customer with journey information, and the Travel Companion enhances the user experience by giving restaurant suggestions and providing special offers. These two systems help to materialise this vision and deliver seamless door-to-door travel support encompassing both public and private transportation. This includes the mentioned functionalities as well as the required tooling and modular design to foster adoption and enable future refinements, new concepts and ideas. The solution developed in ATTRACkTIVE proposed to guide, support, inform, and even entertain users throughout their entire itinerary.

– The aim of the BONVOYAGE (2015-2018) project was to find the best way to go from a place to another, door to door, for passengers and goods, by using any combination of any transport means. The BONVOYAGE platform aimed to integrate travel information and planning and ticketing services, and automatically analyse:

  - non-real-time data from heterogeneous databases (on road, railway and urban transport systems);
  - real-time measured data (traffic, weather forecasts, data from smartphone and wearable sensors);
  - user profiles;
  - user feedback.

The platform was supported by an innovative Information-Centric communication Network (ICN) that collects and distributes the data required to optimize a travel.

– The ongoing CONNECTIVE (2017-2022) project aims to provide a technical framework and a set of tools supporting the digital transformation of the rail, facilitating advances in multimodal travel, eliminating barriers in journeys that mix rail transport with other modes, and improving the fit between demand and supply. It will identify technical requirements, provide tools and methodologies and develop analytics, with the aim to enable seamless integration with all other modes of transport and facilitate rail travel across Europe. The rail interoperability framework (IF) developed by CONNECTIVE will be the key driver for more efficient interconnection across modes and will form the backbone for a future research projects.

– The SPRINT (2018-2020) project extends the rail IF concept to bring the market uptake of the multimodal transport ecosystem closer to reality. It aims to improve its performance and scalability towards a large deployment, and facilitate new services and subsystems integration.

- Focusing on very recent projects that started during the past few months, the ExtenSive will focus to further enhance the traveller experience and improve the travel services in several areas, including travel shopping, trip tracking, booking and ticketing, building and implementing, among else, an intelligent Software as a Service (SaaS) Solution.

6.6.3 Achievements

From the research projects identified above a number of advancements were made in ICT solutions to enhance the rail user experience sub-theme:

- The Co-Active project made progress in the interoperability between different booking and ticketing systems. This included the improvement of scenarios and use cases, which have allowed for one-stop-shop capability enrichment, after-sales services management, and the proposal of a payment-settlement solution for retailed products and services. In terms of software component development, the project partners have developed journey planning and offers software, which enables the user to browse a choice of offers from different modes and operators. Virtual credit card payments have also been developed; enabling a secured and fast clearing between ticket providers and third party retailers.
- The rail travel services project My-TRAC has resulted in the development of a mobile application which creates the best trip recommendation for each user based on their attributes and affective variables. The application was piloted in four locations (the Netherlands, Greece, Portugal and Spain) by users across a period of three to six months. Co-Aps, funded by the European Institute of Innovation and Technology (EIT), is a new mobile application launched to help reduce the spread of the Coronavirus disease 2019 (COVID-19) by managing density in public transport and public spaces. Shift2Rail's My-Trac technology will be used for the demonstration of the application's features, showing a successful institutional collaboration with EIT.
- Project results from the FAIR Stations project included the development of crowd flow analysis tools for the general population, but also considers passengers with restricted mobility. This tool also accounts for baggage handling and security in stations. To date this has achieved TRL2, so still in the stages of early development. Three concepts for independent boarding were developed. One is being developed into details in readiness for prototyping. An evaluation of the door access systems has also been done, which links in with the complementary project PIVOT. This has also been developed to TRL2.
- The two software packages within the ATTRACkTIVE project, the Trip Tracker and the Travel Companion, were developed and resulted in two technical demonstrators. These demonstrators have reached TRL6/7, in line with the objectives set out within the Shift2Rail Innovation Programme 4 (IP4, IT Solutions for Attractive Railway Services). An example trip using the software could consist of notifications through the app to remind the user to change services or, if needed, suggest alternative routes. At the same time, the Travel Experience uses location-based information to propose a range of opportunities. For example, if the passenger has a stopover, the app will provide them with a voucher for a coffee from a nearby vendor.
- Project partners within the BONVOYAGE defined a new distributed way for travel optimisation, which includes local-optimal solutions in multimodal and cross-border itineraries. A user-profiler tool was also developed, which is able to jointly take into account the user request and the feedback choice carried out by the user as he or she selects one or more travel solutions. It is also able to exploit crowd-sourced data for automatic identification of users' behaviour in terms of on-trip user stress level and current transportation mode, by data analysis models applied to data coming from sensors and smartphones. By properly combining user feedbacks and orchestration, the BONVOYAGE planning service is the first able to benefit from such a user profiling in a distributed environment.

6.6.4 Implications for future research

The My-Trac project resulted in further exploration of the rail travel services to help manage passenger density in public transport hubs during the COVID-19 pandemic. Further research could be conducted in this area to allow passengers to select their preference for travel options based on their willingness to be in crowded spaces. Information could be passed to the user on how busy the stations are currently (and perhaps how busy they will be throughout the day), and from which a new suggested route would be created based on user preferences

The development of a crowd flow analysis tool which also considers passengers of restricted mobility reached TRL2 within the FAIR Stations project. This indicates that there is some way to go in this area in terms of further research. The concepts developed in the project could be developed to demonstration phase, which would allow for specific benefits of the technology to be quantified in practice.

The rail IF ecosystem developed and improved by CONNECTIVE and SPRINT projects can be used in technology demonstrators to advance multimodal door-to-door experiences. It is expected that the groundwork developed by CONNECTIVE will be exploited in future research projects.

6.6.5 Implications for future policy development

Improving the rail experience for passengers with restricted mobility has been considered within the FAIR Stations project. As the research in this area is relatively undeveloped, further policy could help to develop the technologies further. All new public transport hubs could be encouraged to implement these technologies, which aid passengers with restricted mobility and could greatly improve the user experience for these passengers.

There are several multimodal travel and ticketing services being developed in the research projects. There is a risk that all of the different travel applications are incompatible with each other, resulting in users needing to download a different application for every new city they visit. Whilst this is being investigated within the Co-Active project, future policy could aid the development of more regional travel applications, which could work within an entire country or perhaps even across several MSs. This would allow a central body to manage all of the data and ensure that it is protected and secure.

7 Insight from academia and industry

This section focuses on research trends from the academia and technology trends from the Industry. For the first, the Scopus citation database for scientific research[44] has been used, while the second uses data obtained from the European Patent Office (EPO) Worldwide Patent Statistical Database (PATSTAT[45]), appropriately elaborated for TRIMIS.

7.1 Analysis of scientific research

This exercise aims to assess the global evolution of peer reviewed scientific publications in the area of rail transport in the last years, thus providing a perspective also beyond Europe. For the exercise, the Scopus citation database for scientific research has been used. The analysis was performed in January 2021 and has been limited to journal publications for the 10-year period 2011-2020. These analyses focus on regular expressions (REGEX), representative[46] of the sub-themes defined in rail transport research. The complete REGEX list used is reported in Annex 2, while Table 16 provides the connection between the sub-themes defined in this report and some of the expressions used, as well as the number of documents reported in the 10-year period.

Table 16. Rail research sub-themes and scientific research expressions

Rail transport sub-theme	Expressions	Number of documents
Efficient stock design and manufacturing	stock; wagon; materials	1 653
Emissions and noise reduction	noise reduction; energy management; energy saving; energy efficiency; alternative energy	1 247
Track and stock maintenance	track maintenance; rail maintenance; stock maintenance; wagon maintenance; infrastructure maintenance; predictive maintenance; condition monitoring	722
Efficient rail operations	connected technologies; EGNSS (European Global Navigation Satellite System); ERTMS; GSM-R (Global System for Mobile Communications - Railway); signalling system; automatic train protection; rail operation	521
Infrastructure management	infrastructure management; multimodal infrastructure; infrastructure safety; station design; catenary system; interoperability; electromagnetic compatibility; sleeper design	504
ICT solutions to enhance the rail travel experience	ticketing; multimodal trip; smartphone; accessibility	938

Source: TRIMIS

The figures below provide the results focusing on number of documents per year and their country of origin. A trend line has been added to the number of documents per year to highlight the trend. In the country-of-origin figures, the documents that come from the EU27 countries have been combined in a single bar. Nevertheless, it should be noted that in the same time span, there has been an increase of publications in the science areas in Scopus considered in this exercise. As a comparison, and with 2010 as a reference, the total number of scientific publications increased by 20% in 2016 and by 40% in 2020.

On the *efficient stock design and manufacturing* sub-theme, as Figure 23 shows, the publication trend is positive, evolving from 116 documents in 2011 to 220 documents in 2020. China (CN) is leading in terms of research outputs, with the United Kingdom and the United States following, while Italy, Germany, and Spain are three EU27 countries that make it into the top 10.

The *emissions and noise reduction* sub-theme, as can be seen in Figure 24, identifies a positive trend, passing from around 72 documents in 2011 to 194 documents in 2020. China is leading in terms of research outputs also in this case, with Japan (JP) and the United States following, while Italy, Spain and Germany are the three EU27 countries that make it into the top 10.

[44] www.scopus.com (accessed on 2 March 2021)
[45] https://www.epo.org/searching-for-patents/business/patstat.html (accessed on 2 March 2021)
[46] Regular expressions are intended to be representative of each sub-theme but not necessarily exhaustive.

On the *track and stock maintenance* sub-theme, in Figure 25 the trend is positive evolving from a low of 31 documents in 2011 to 147 documents in 2020. China is the country with the majority of publications, followed by the UK. Sweden (SE), Italy, The Netherlands (NL) and Germany are the four EU27 countries that appear in the world top 10.

When looking at the *efficient rail operations* sub-theme, illustrated in Figure 26, the positive trend is not so marked: from 51 documents in 2011 to 61 documents in 2020. The majority of publications comes from: China. Italy, Spain, France and Germany are the four EU countries in the top 10.

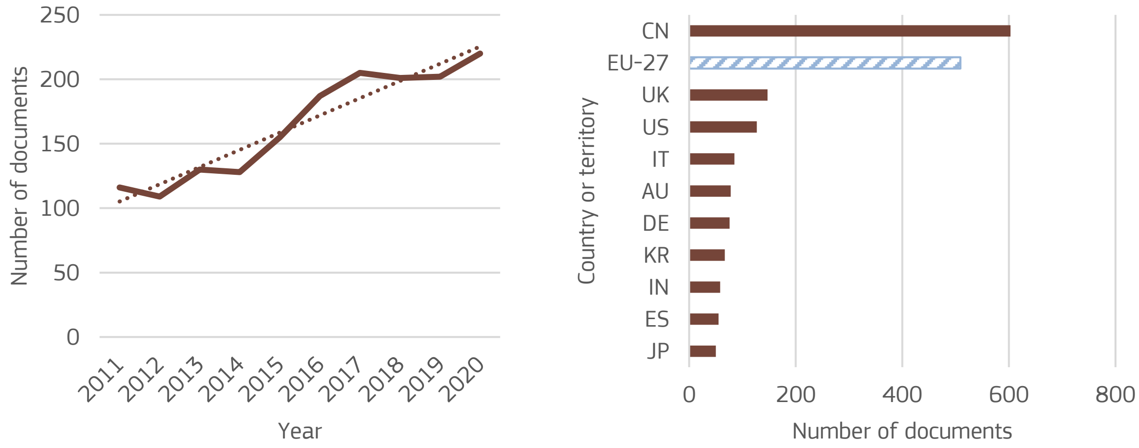
On the sub-theme *infrastructure management* (Figure 27) the trend is positive, evolving from a low of 18 documents in 2011 to 73 documents in 2020. China is again leading, closely followed by the US. Italy, Spain, Germany, France, Sweden and Poland (PL) are six EU27 countries that make it into the top 10.

Finally, on the *ICT solutions to enhance the rail travel experience* sub-theme (Figure 28), the trend is very positive evolving from a low of 47 documents in 2011 to 172 documents in 2020. China is leading, followed by the US, Spain, Italy and The Netherlands are the three EU27 countries that make it into the top 10.

From the analysis, as a general remark, China seems to dominate in rail transport research in the last years. However, Europe is strong: if the EU27 countries were considered all together, in many cases they would become the leading entity.

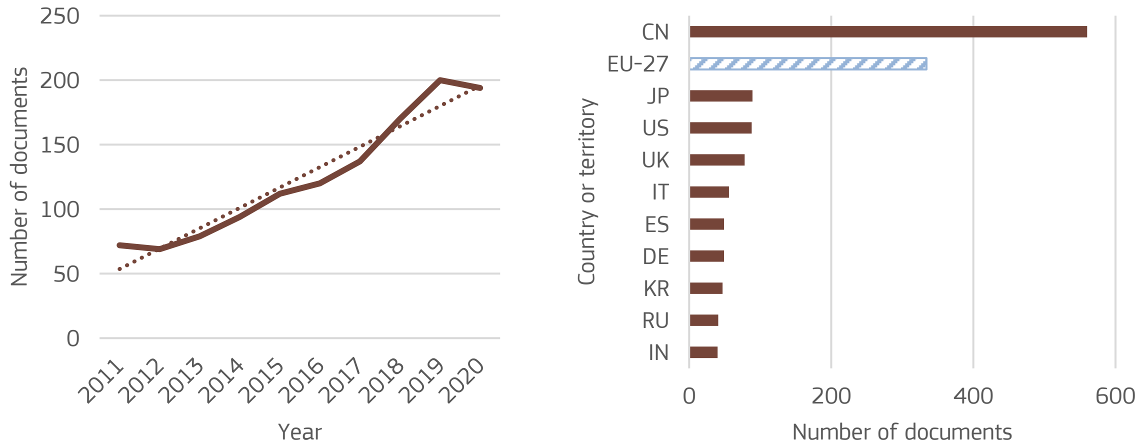
The results provide in this section need to be read with caution as the expression chosen with REGEX may suffer from some limitations, not covering the entire themes. Nevertheless, despite the limitations, the results provided in this section, provide a meaningful analysis of research trends in rail transport research.

Figure 23. Research documents 2011-2020 (left) and country of origin (right) on efficient stock design and manufacturing



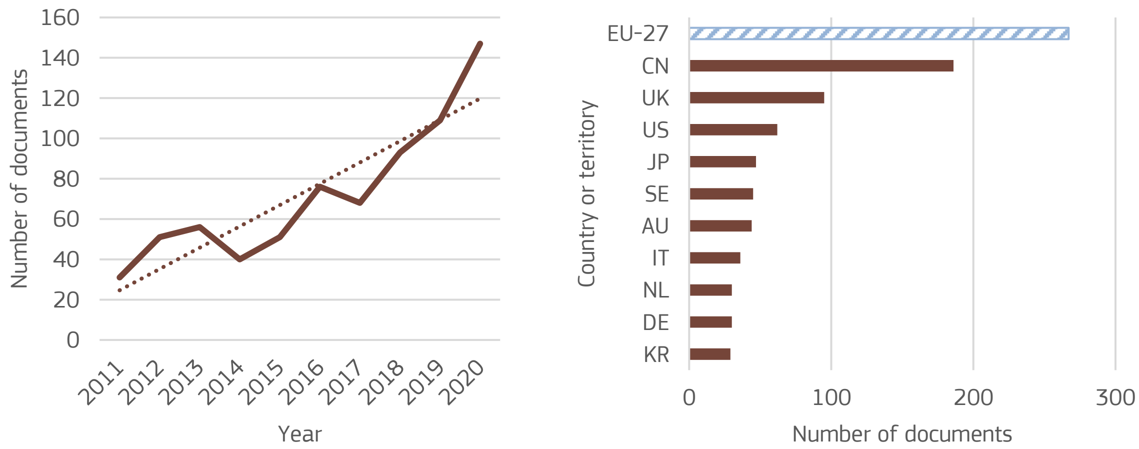
Source: TRIMIS elaborations based on Scopus

Figure 24. Research documents 2011-2020 (left) and country of origin (right) on emissions and noise reduction



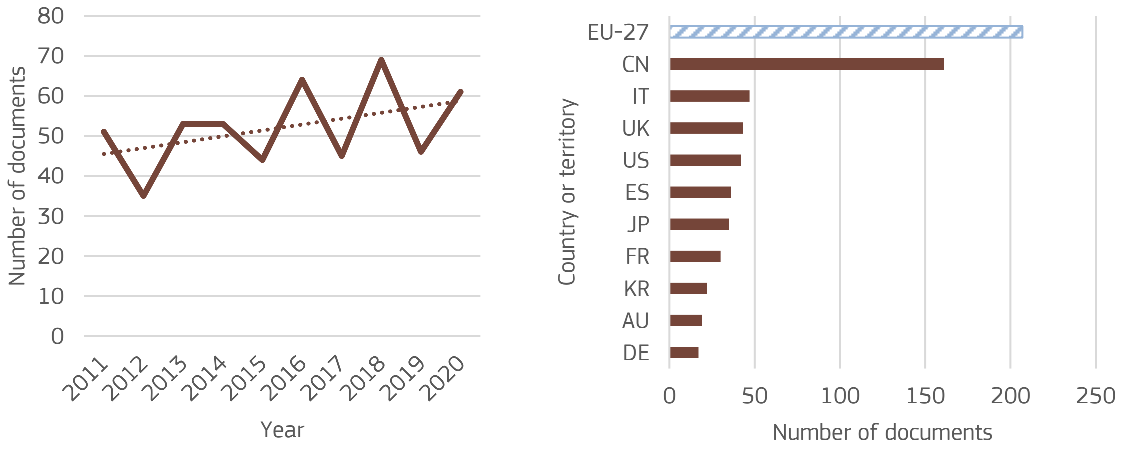
Source: TRIMIS elaborations based on Scopus

Figure 25. Research documents 2011-2020 (left) and country of origin (right) on track and stock maintenance



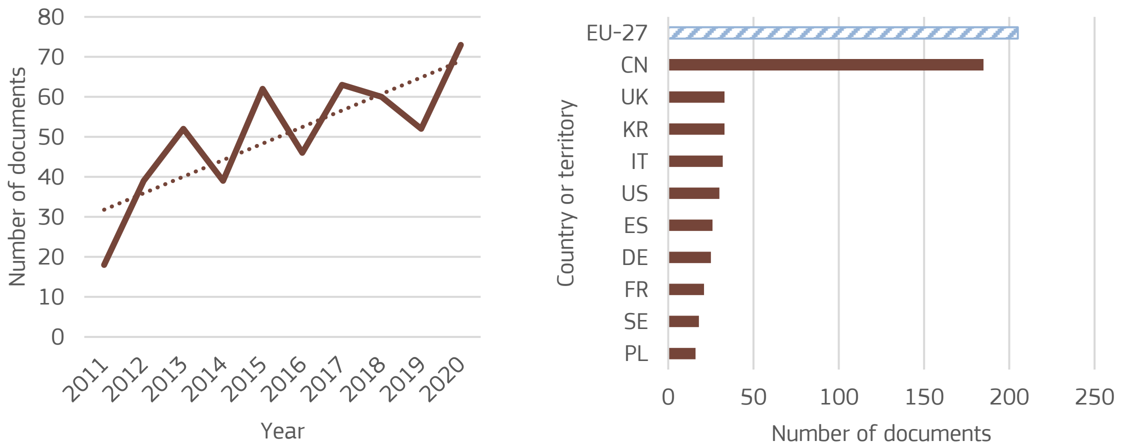
Source: TRIMIS elaborations based on Scopus

Figure 26. Research documents 2011-2020 (left) and country of origin (right) on efficient rail operations



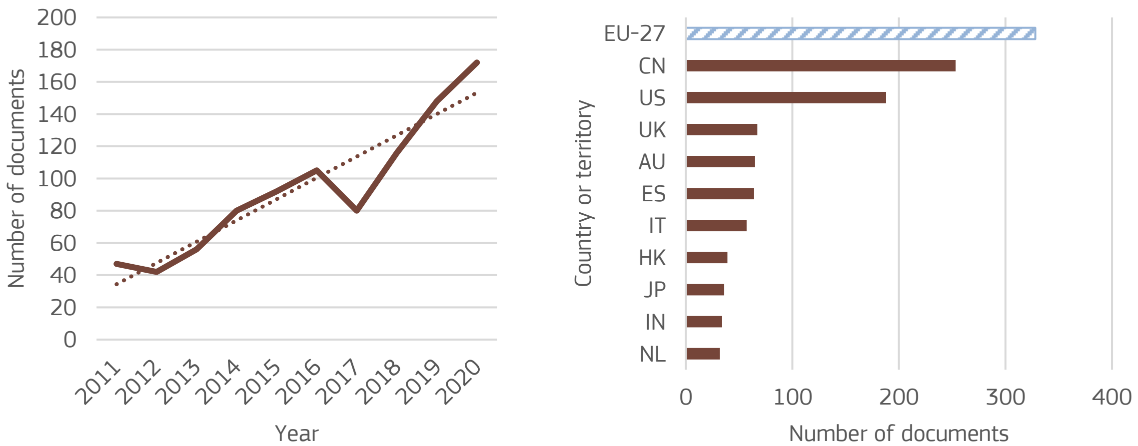
Source: TRIMIS elaborations based on Scopus

Figure 27. Research documents 2011-2020 (left) and country of origin (right) on infrastructure management



Source: TRIMIS elaborations based on Scopus

Figure 28. Research documents 2011-2020 (left) and country of origin (right) on ICT solutions to enhance the rail travel experience



Source: TRIMIS elaborations based on Scopus

7.2 Analysis of patents

Patent analysis aims to provide additional insight into private investments and research outputs related to technological topics. This assessment focuses on the analysis of international patent applications related to the rail transport research topics and sub-topics. For this purpose, PATSTAT was used, and a search using CPC codes, patent title and abstract was carried out.

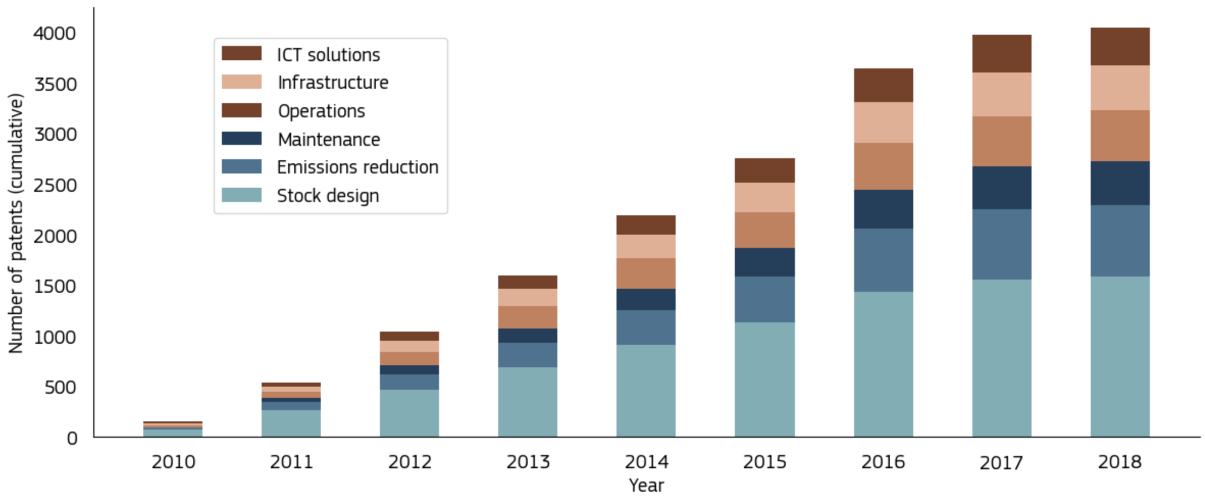
For this exercise, the search was restricted to different CPC codes for each sub-theme, with the main overarching class being the code B61 – RAILWAYS. The search period was from 2010 to 2018. Table 17 shows the keywords and CPC codes used for the search for each sub-theme and 59 shows the cumulative sum per year for the search period. Figure 29 provides an overview of transport granted patents per sub-theme based on application year.

Table 17. Sub-themes and keywords used for patent search

Rail transport sub-theme	Subclass	Regular Expressions
Efficient stock design and manufacturing	B61C; B61D; B61F; B61G; B61H; B60L	'wagon', 'stock', 'door', 'suspension', 'lightweight' , 'brake'
Emissions and noise reduction	B61	'noise', 'vibration', 'energy', 'energy management', 'energy saving', 'efficiency', 'alternative energy', 'management'
Track and stock maintenance	B61	'maintenance', 'rail maintenance', 'stock maintenance', 'wagon maintenance', 'infrastructure maintenance', 'predictive maintenance', 'condition monitoring', 'detection'
Efficient rail operations	B61	'communication', 'automatic train operation', 'connected technology', 'EGNSS', 'ERTMS', 'GSM-R', 'signalling system', 'automatic train protection', 'rail operation', 'safe train positioning', 'safe train positioning', 'cyber', 'security'
Infrastructure management	B60M, B61	'infrastructure', 'multimodal', 'infrastructure safety', 'station', 'catenary' , 'interoperability', 'electromagnetic compatibility', 'sleeper'
ICT solutions to enhance the rail travel experience	B61	'ticket', 'multimodal', 'trip', 'smartphone', 'application', 'software', 'accessibility', 'electronic', 'customer experience', 'booking'

Source: Own elaborations based on data from the European Patent Office (EPO)

Figure 29. Rail transport granted patents per sub-theme based on application year: cumulative sum between 2010 and 2018



Source: Own elaborations based on TRIMIS and PATSTAT

From the results, it can be seen that the highest number of patents belongs to *Stock design*, followed by *Emissions reduction*, while the remaining sub-themes have a similar share of patents. The increase in number of patents is relatively linear until 2016. This can be explained by the time lag between a patent application and it being granted. Thus, it is expected that the numbers for the latest years shall increase as more applications are granted.

A forthcoming joint study by ERA and JRC (ERA - JRC, 2021) will explore the role of innovation and patents in the railway sector, with a specific focus on Europe, by investigating patent statistics from different perspectives.

8 Conclusions

Focusing mainly on selected EU funded projects starting from FP7 and H2020, this report presents a comprehensive analysis of rail R&I 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:

Focusing on rail related projects in the TRIMIS database and the STRIA coverage:

- There are 526 projects under the rail transport mode in TRIMIS in total. Most of these projects have a duration of 3 or 4 years, with a steady increase in the number of projects since 1995, while the majority of projects started in the periods corresponding to the latest two European FPs, FP7 and H2020. Funding peaked in 2020 with an annual total value for projects of a bit less than 120 million, while the maximum number of projects commenced was observed in 2017 (137 projects).
- An analysis of STRIA roadmap categories within rail projects shows that, the *transport infrastructure* roadmap has the highest number of projects, followed by *network and traffic management* and *vehicle design and manufacturing*. These last two, however, have a high number of projects linked to multiple roadmaps.

Focusing on rail projects selected for this assessment:

- Focusing on European countries involvement in FP research, organisations from the five most active countries attract almost 75% of total EU contributions directed to rail R&I projects. German entities acquired €147 Million and are the leaders, followed by Spain, France, Italy and the UK. Central and East European countries have the lowest participation rates and in consequence, organisations from these countries receive substantially less funding.
- High EC contributions are directed to regions of Belgium, the western part of the Netherlands, and the UK. Moreover, the highest amount of funding goes to organisations located in the capital regions (e.g. Madrid, Paris, Berlin) as well as some other bigger metropolitan areas of Western and Central European countries (e.g. Bilbao, Genova, Munich).
- There are in total 953 organisations involved in 194 analysed projects, out of which 898 are located within EU27 or the UK. The countries with the largest portfolio of different organisations involved in rail R&I projects are Germany and Spain (131 and 130 unique organisations respectively), Italy (110) and France (96).
- Organisations coming from five countries participated the most in the analysed rail R&I projects: Germany, Spain, Italy, France and the UK. Even though representatives of these countries often led the consortium, Belgium is the country with the highest number of projects led. Moreover, there is a clear division between these six countries and the others in terms of leading a consortium: organisations from only nine other countries led projects, but in any case, no more than five.
- Looking at the links between leaders of consortium and project partners located in different countries, there is a significant imbalance in leadership involvement between entities coming from Belgium compared to other countries. For example, there are many more project partners from Italy, France, Spain or Germany in projects led by entities coming from Belgium than the other way round (Italy: 100 vs 19; France: 77 vs 24; Spain: 65 vs 10; Germany: 61 vs 14 respectively). On the other hand, there is relative equilibrium between partners from other countries, and usually the number of partners in projects led by representative of a given country are similar.
- The high number led projects by Belgium's actors is related to a very high activity of UNIFE – this institution alone led more projects than all organizations from France or the UK. It took part in roughly 25% of all analysed R&I projects, with only Germany's DB participating in comparable number of projects. These two organisations are closely followed by a group of entities, which took part in more than 30 projects each. This data shows that relatively few organizations actively participated in many projects. Moreover, these high numbers of projects implemented with participation of a particular organization were possible due to the fact that rail projects were realized by large consortia. Each project was realized by 12.8 project partners on average, however the largest ones involved around 50 organizations. On the contrary, more than 600 organisations (67% of all organisations involved) took part in only one project and roughly 86% of them – in no more than three.

Focusing on technologies from the TRIMIS technology database:

- Among the top-20 rail technologies, eight are linked only to rail while five are linked also to multimodal transport. Five technologies received each a funding of above 50 million: *collaborative logistics ecosystem*, *self diagnosis smart sensors and smart running gear*, *Decision Support Tools for infrastructure management*, *more efficient rail wagons*, and, *education and research in the railway sector*. Those technologies linked to more transport modes are likely to give a partial view on rail research.
- Looking at the top-3 rail technologies in terms of projects that research them, *railway technological infrastructures* is researched in 12 projects in the TRIMIS database. The *noise simulation and mitigation for reduced vibration* technology, is researched in eight projects, and, *advanced train control systems* have been researched in eight projects.

More specific findings focus on the R&I from the six sub-themes thoroughly analysed in Section 6.

On the efficient stock design and manufacturing sub-theme:

- Focusing on achievements from the selected R&I projects:
    - Results on the use of lightweight materials for railway carbody shells showed that the external geometry of the car body can reduce the total weight by up to 20%.
    - The design of a SiC technology traction converter for tramway applications as well as for metro applications may lead to reduced energy consumption (and therefore reduced carbon emissions) and savings from reduced maintenance needs.
    - A prototype lightweight vehicle has been designed, built and tested on a special track, along with upgraded infrastructure, which reduced energy consumption of the locomotive.
    - A multifunctional smart wagon and facilities were developed and have proved to simplify and speed up the loading and unloading operations of freight wagons, allowing for increased multimodality and reduced cycle-times.
    - An innovative axlebox has been produced, with the required mechanical properties of a standard axlebox, but 30% lighter and smaller than current state-of-the-art.
- Focusing on implications for future research:
    - Future research could explore the use of lightweight vehicles not only in freight applications but in passenger applications as well. The research could explore the suitability of lightweight materials in passenger carriages to reduce energy consumption in passenger rail.
    - The use of silicon carbide in railway applications has reached the prototyping phase. Future research could focus on bringing the promising technology to implementation phase through demonstration of the technology.
    - The use of SiC technology has been investigated in tramway and metro applications. Future research could focus on the applications for other railway modes, such as high-speed passenger rail and freight services.

On the emissions and noise reduction sub-theme:

- Focusing on achievements from the selected R&I projects:
    - Efficient mitigation measures that allow more freight rail traffic and fewer negative effects were designed and validated, using different measures (by picking up excessive vibration from wagons, locomotives and track sections, by replacing wooden or concrete sleepers with ladder track or similar track structures, and, using soil barriers)
    - Significant rail noise reduction (by at least 6 dB(A)) was achieved through the integration of low-frequency noise emission and the actual wheel rail contact conditions, and, on-board monitoring systems based on noise measurements and location sensors were developed.

- An innovative technology for visualisation of noise scenarios was developed, which gives the possibility of listening and experiencing visually the noise of trains passing on a certain track at the early design phase, together with a proposal for eco-labelling.
- Technological innovations improving energy performance for engines were developed, together with a decision support software for rail engineers and others involved in urban rail management.
- Common KPIs and technical recommendations were delivered that will help rail networks reach energy efficiency targets and lead to more sustainable public rail systems in Europe.
- Main railway noise sources were identified and ranked in real operation conditions on the Valencia network. A developed follow-up model was capable of predicting certain design changes for light rail tram systems.

— Focusing on implications for future research:

- The idea proposed for eco-labelling for railway systems based on stakeholder analysis could be explored further, as eco-labels can encourage end-users to select more efficient and environmentally friendly systems.
- Perhaps the use of a lifecycle cost label in addition to the eco-label could encourage users further to select efficient systems as they could see cost benefits along with emission savings.

On the track and stock maintenance sub-theme:

– Focusing on achievements from the selected R&I projects:

- A laser-based trolley and the associated algorithms have been developed for assessing switches and crossings, together with a switch inspection device that will also be able to monitor tack geometry. All these, safely and without rail traffic disruption.
- A track monitoring system for condition-based track maintenance has been developed and initial commercial success of the product has been achieved, with several commercial contracts either in operation or being shipped. The system consists in a lightweight workstation, adapted to the most common rail gauges in the EU.
- Deterioration of the structural integrity of axle bearings can be detected using temperature, vibration and low and high-frequency acoustic emission measurements using sensors installed either on each axle bearing or wayside. On-board monitoring systems composed by temperature sensors, accelerometers and acoustic emission were demonstrated as prototypes. These can improve the reliability of rolling stock and increase the cost-efficiency of maintenance activities based on condition-based maintenance rather than corrective.

– Focusing on implications for future research:

- Many of the research projects under the track and stock maintenance sub-theme are already well developed, reaching implementation phases. Track inspection technologies developed within some projects could be consolidated with an aim to create a combine track inspection system, which pulls together components from each project into one system.
- Cloud-based maintenance systems are also being explored for passenger vehicle applications. Learnings could be taken from passenger cloud maintenance systems and applied to rail applications, and vice versa, through future research. This would also help with the interoperability between rail and road cloud-based maintenance systems.

On the efficient rail operations sub-theme:

– Focusing on achievements from the selected R&I projects:

- The Shift2Rail X2RAIL-1 and the follow-on project X2RAIL-2 researched and developed several key technologies in the field of railway signalling and automation systems. Specific objectives included adapting radio communication systems to allow for more advanced rail automation systems, to improve train punctuality through more extensive use of automatic train operation systems, to ensure the backward compatibility of the ERTMS/ETCS technologies, and to ensure security among all connected signalling and control systems by developing new cyber security systems dedicated to railways. In addition, fail-safe train positioning based on multi-sensor concept utilising GNSS, on-board train integrity to allow the application of new signalling train separation concepts, standardisation of signalling project phases, and improve standardisation and integration of traffic management processes.

- Within projects under this sub-theme, modelling tools were developed for intelligent AC power supply systems, which will enable lower energy usage and reduced energy losses through the power supply systems. A number of novel formation treatments has been investigated with respect to improving the track support structure under the optimised track system work package.
- Several field tests using obstacle detection systems were conducted on rail track sites, advancing the current state of art and detecting obstacles beyond 200m and up to 1 000m in some cases.
- Equipment has been developed, leading to more realistic testing of ETCS components, whilst reducing certification time and cost and increasing safety and availability.

— Focusing on implications for future research:

- Future research could investigate the further development and testing of technologies to enhance and accelerate the transition from ETCS level 2 to level 3.
- Further research into the possible prototyping and demonstration of the real-time yard management system could be conducted to quantify the benefits of obstacle detection systems in terms of efficiency gains.

On the infrastructure management sub-theme:

- Focusing on achievements from the selected R&I projects:
  - Improved energy management solutions have been researched and applied in case studies, together with the evaluation of standardisation and calibration of energy meters and information exchange protocols between components from on-board energy meters to smart grid components.
  - The possibility to charge electric vehicles using power from the metro systems has been tested.
  - A simple trolley wire system for mainline use for vehicle speeds of up to 100 km/h has been tested, and, a very low-cost, self-powered monitoring equipment for electromechanical interlocking systems still used for lower-density lines has been developed and demonstrated.
  - An integrated toolbox has been developed, targeted at different types of level crossing. These tools can be as simple as speed bumps before a crossing, paint or optical effects that slow drivers.
  - Three most probable classes of EM attack on the railway have been identified, with the jamming of information transmitted between system components being the most credible. A protection solution has been proposed that combines robust communications architecture with an attack management sub-system.
- Focusing on implications for future research:
  - Railway energy management systems could be developed further to investigate an energy management system for the railway when it is being utilised to charge electric vehicles.
  - Future research could investigate the possible but technically difficult probable classes of EM attacks.

On the ICT solutions to enhance the rail travel experience sub-theme:

- Focusing on achievements from the selected R&I projects:
  - Progress has been made in the interoperability between different booking and ticketing systems, including the improvement of scenarios and use cases, which have allowed for one-stop-shop capability enrichment, after-sales services management, and the proposal of a payment-settlement solution for retailed products and services.
  - A mobile application which creates the best trip recommendation for each user based on their attributes and affective variables has been development and piloted by users.

- A new mobile application was launched in 2020 to help reduce the spread of COVID-19 by managing density in public transport and public spaces.
- Crowd flow analysis tools for the general population were developed, considering also passengers with restricted mobility and accounting for baggage handling and security in stations.
- Two software packages were developed and resulted in two technical demonstrators, reaching high TRL. Using this software, an example trip could consist of notifications through the app to remind the user to change services or, if needed, suggest alternative routes. At the same time, location-based information help to propose a range of opportunities during the trip.
- A planning service has been developed, the first of its kind able to benefit from extensive user profiling in a distributed environment, taking into account the user request and feedback as well as being able to exploit crowd-sourced data.

— Focusing on implications for future research:

- Further research could be conducted in rail travel services to allow passengers to select their preference for travel options based on their willingness to be in crowded spaces. Information could be passed to the user on how busy the stations are currently (and perhaps how busy they will be throughout the day), and from which a new suggested route would be created based on user preferences
- The development of a crowd flow analysis tool, which also considers passengers of restricted mobility could be developed to demonstration phase, which would allow for specific benefits of the technology to be quantified in practice.

— Focusing on insight from academia and industry

- From an analysis of scientific research deriving from the Scopus database, findings support that there is positive trend in rail academic research, with *ICT solutions to enhance the rail travel experience* being the sub-theme that experienced the highest increase in publications in the last decade. As a general remark, China seems to dominate in rail transport research in the last years. However, Europe is strong: if the EU27 countries were combined in the analysis, for most of the sub-themes they would become the leading entity.
- Using data from PATSTAT, it was found that the highest number of patents belongs to the *efficient stock design and manufacturing* sub-theme, followed by *emissions and noise reduction*, while the remaining sub-themes have a similar share of patents. The increase in number of patents is relatively linear until 2016. This can be explained by the time lag between a patent application and it being granted. Thus, it is expected that the numbers for the latest years shall increase as more applications are granted.

Some final considerations can be made about the way forward for rail R&I. A number of Shift2Rail R&I projects from the 2020 annual work plan and budget have commenced in December 2020, with findings expected in 2021 and beyond. At the same time, the Shift2Rail's annual work plan and budget 2021[47] provides the priorities for future research that will focus on the ERTMS game changers, on reaching higher TRL level towards demonstrators, on exploring new areas and technologies and on preparing the transition to the next programming period and Europe's Rail JU. During 2021, no significant Call for Proposal is foreseen by Shift2Rail.

It is expected that Europe's Rail, the JU replacing Shift2Rail will focus on digital innovation and automation to achieve the radical transformation of the rail system needed to deliver on the European Green Deal objectives[48].

[47] https://shift2rail.org/wp-content/uploads/2020/12/GB-Decision-08-2020_Annex_AWP-2021.pdf (accessed on 26 February 2021)
[48] https://shift2rail.org/news/europes-rail-joint-undertaking-proposed-by-the-european-commission-to-the-european-council-and-parliament (accessed on 26 February 2021)

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List of abbreviations and definitions

3D	Three-dimensional
5G	5th generation mobile networks
AC	Alternating current
AI	Artificial Intelligence
ALS	Alstom Transport SA
ALT	Low-emission alternative energy for transport
AT	Austria
ATO	Automated train operation
ATP	Automatic Train Protection
B2B	Business to Business
B2C	Business to Consumer
BE	Belgium
BG	Bulgaria
CAT	Connected and automated transport
CBA	Cost-benefit analysis
CBM	Condition based maintenance
CBTC	Communications-based train control
CE	Conformite Europeenne
CEF	Connecting Europe Facility
CHIRP4Rail	Collaborative tHreat Intelligence Platform for Rail
CO_2	Carbon Dioxide
COVID-19	Coronavirus disease 2019
CORDIS	Community Research and Development Information Service
CPC	Cooperative Patent Classification
CSA	Coordination and Support Action
CSIRT	Computer Security Incident Response Team
CY	Cyprus
CZ	Czechia
db(A)	A-weighted decibels
DB	Deutsche Bahn
DE	Federal Republic of Germany
DG MOVE	Directorate-General for Mobility and Transport
DG RTD	Directorate-General for Research and Innovation
DK	Denmark
DLR	Forschungszentrum der Bundesrepublik Deutschland für Luft- und Raumfahrt
DOT	Department of Transportation
DSS	Decision Support System
EE	Estonia

EGNSS	European Global Navigation Satellite System
EIT	European Institute of Innovation and Technology
EL	Greece
ELT	Transport electrification
EM	Electromagnetic
END	European Noise Directive
EPO	European Patent Office
ERA	European Union Agency for Railways
ERTMS	European rail traffic management system
ES	Spain
ETCS	European Traffic Control System
EU	European Union
EU27	European Union of 27 Member States
EU28	European Union of 28 Member States
FRP	Fibre Reinforced Polymers
FP	Framework Programme
FP7	7th Framework Programme
FR	France
FI	Finland
FST	Fire, Smoke & Toxicity
GHG	Greenhouse Gas
GNSS	Global Navigation Satellite System
GoA	Grade of Automation
GSM-R	Global System for Mobile Communications – Railway
H2020	Horizon 2020 Framework Programme
HMI	Human Machine Interface
HR	Croatia
HU	Hungary
IAMS	Intelligent Asset Management Systems
ICN	Information-Centric communication Network
ICT	Information and Communications Technologies
IE	Ireland
IF	Interoperability Framework
INF	Transport infrastructure
IP	Intellectual Property
IPs	Innovation Programmes
IT	Italy
ITDs	Integrated Technology Demonstrators
KPI	Key Performance Indicator

JRC	Joint Research Centre
JU	Joint Undertaking
LiDAR	Light Detection and Ranging
LT	Lithuania
LU	Luxemburg
LV	Latvia
MaaS	Mobility as a Service
MS	Member States
NGTC	Next Generation Train Control
NL	Netherlands
NR	Network Rail Infrastructure Limited
NTM	Network and traffic management systems
NUTS	Nomenclature of Territorial Units for Statistics
NUTS2	Nomenclature of Territorial Units for Statistics level 2 codes
NUTS3	Nomenclature of Territorial Units for Statistics level 3 codes
ÖBB	Austrian Federal Railways
OD	Obstacle Detection
OTPA	Operational transfer path analysis
PATSTAT	European Patent Office Worldwide Patent Statistical Database
PL	Poland
PT	Portugal
PTI	Platform train interface
RAMS	reliability, availability, maintainability and safety
REGEX	Regular expressions
RO	Romania
R&D	Research and Development
R&I	Research and Innovation
SaaS	Software as a Service
S&C	Switches and crossings
SE	Sweden
SERA	Single European Railway Area
SNCF	Société nationale des chemins de fer français
S2R JU	Shift2Rail Joint Undertaking
SI	Slovenia
SiC	silicon carbide
SIE	Siemens Aktiengesellschaft
SIL	Safety integrity level
SK	Slovakia
SMO	Smart mobility and services

SRIA	Strategic Research and Innovation Agenda
SSMS	Sustainable and Smart Mobility Strategy
STPS	Smart train positioning system
STRIA	Strategic Transport Research and Innovation Agenda
STS	Hitachi Rail STS S.p.A
SWD	Staff Working Document
S&C	switches and crossings
TCMS	Train Control and Monitoring System
TDs	Technology Demonstrators
TEN-T	Trans-European Transport Network
TID	Track Intrusion Detection
TMS	Traffic Management System
TRIMIS	Transport Research and Innovation Monitoring and Information System
TRL	Technology Readiness Level
TRV	Trafikverket
TSI	Technical Specification for Interoperability
UIC	Union internationale des chemins de fer
UK	United Kingdom
UNIFE	The Association of the European Rail Industry
US	United States
VDM	Vehicle design and manufacturing
VR	Virtual Reality

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Annexes

Annex 1. Project tables

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	Efficient stock design and manufacturing	Emissions and noise reduction	Track and stock maintenance	Efficient rail operations	Infrastructure management	ICT solution to enhance the rail travel experience
4SECURAIL	FORMAL METHODS AND CSIRT FOR THE RAILWAY SECTOR	2019-2021	Shift2Rail				Y		
AB4RAIL	Alternative Bearers for Rail	2021-2022	Shift2Rail				Y		
ACEM RAIL	Automated and Cost Effective Maintenance for railway	2010-2013	FP7 TRANSPORT			Y			
ACOUTRAIN	Virtual certification of acoustic performance for freight and passenger trains	2011-2014	FP7 TRANSPORT	Y	Y				
AEROTRAIN	AEROdynamics Total Regulatory Acceptance for the Interoperable Network	2009-2012	FP7 SST	Y					
ALARP	A railway automatic track warning system based on distributed personal mobile terminals	2010-2013	FP7 TRANSPORT					Y	Y
Andromeda	Predictive Maintenance for railway switches. Smart sensor networks on a machine learning analytics platform	2017-2019	H2020-EU.3.4.; H2020-EU.2.1.; H2020-EU.2.3.				Y		
ARCC	Automated Rail Cargo Consortium: Rail freight automation research activities to boost levels of quality, efficiency and cost effectiveness in all areas of rail freight operations	2016-2021	Shift2Rail	Y			Y		
Assets4Rail	Measuring, monitoring and data handling for railway assets; bridges, tunnels, tracks and safety systems	2018-2021	Shift2Rail			Y		Y	
ASTRail	ASTRail - SAtellite-based Signalling and Automation SysTems on Railways along with Formal Method and Moving Block validation	2017-2019	Shift2Rail				Y		

ATTRACkTIVE	Advanced Travel Companion and Tracking Services	2016-2019	Shift2Rail						Y
AUTOMAIN	Augmented Usage of Track by Optimisation of Maintenance, Allocation and Inspection of railway Networks	2011-2014	FP7 TRANSPORT			Y	Y		
B4CM	Blockchains as a distributed ledger for attribution of RCM data in rail	2018-2021	Shift2Rail				Y		
BioRail	Biocementation for railway earthworks	2019-2021	H2020-EU.1.3			Y		Y	
BONVOYAGE	From Bilbao to Oslo, intermodal mobility solutions and interfaces for people and goods, supported by an innovative communication network	2015-2018	H2020-EU.3.4						Y
BRIDGEMON	Bridge Safety Monitoring	2012-2014	FP7 SME			Y			
CAPACITY4RAIL	Increasing Capacity 4 Rail networks through enhanced infrastructure and optimised operations	2013-2017	FP7 TRANSPORT					Y	
CARBODIN	Car Body Shells, Doors and Interiors	2019-2021	Shift2Rail	Y	Y				
CARGOVIBES	Attenuation of ground-borne vibration affecting residents near freight railway lines	2011-2014	FP7 TRANSPORT		Y				
CLEANER-D	Clean European rail - diesel	2009-2014	FP7 TRANSPORT		Y				
CO-ACTIVE	CO-modal journey re-ACcommodation on associated Travel serVices	2016-2019	Shift2Rail					Y	Y
COHESIVE	COHErent Setup and Demonstration of Integrated Travel SerVices	2017-2022	Shift2Rail					Y	Y
CONNECTA	CONtributing to Shift2Rail's NExt generation of high Capable and safe TCMS and brAkes. Phase 1.	2016-2018	Shift2Rail	Y	Y		Y		
CONNECTA-2	CONtributing to Shift2Rail's NExt generation of high Capable and safe TCMS. PhAse 2.	2018-2021	Shift2Rail	Y	Y		Y		
CONNECTA-3	CONtributing to Shift2Rail's NExt generation of high Capable and safe TCMS PhAse 3	2020-2023	Shift2Rail	Y	Y		Y		
CONNECTIVE	Connecting and Analysing the Digital Transport Ecosystem	2017-2022	Shift2Rail					Y	Y
CYRail	Cybersecurity in the RAILway sector	2016-2018	Shift2Rail					Y	Y

DAYDREAMS	Development of prescriptive AnalYtics baseD on aRtificial intElligence for Iams	2020-2023	Shift2Rail			Y			
DESTINATE	Decision supporting tools for implementation of cost-efficient railway noise abatement measures	2016-2018	Shift2Rail		Y				
DESTinationRAIL	Decision Support Tool for Rail Infrastructure Managers	2015-2018	H2020-EU.3.4				Y		
DIAMOND	Revealing fair and actionable knowledge from data to support women's inclusion in transport systems	2018-2021	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.; H2020-EU.2.1.; H2020-EU.2.3.			Y			
DINTRA	Innovative railway sleeper design increasing track lateral resistance, reducing significantly costs related to track misalignment events	2017-2020	H2020-EU.3.4.; H2020-EU.2.1.; H2020-EU.2.3.			Y		Y	
D-RAIL	Development of the Future Rail Freight System to Reduce the Occurrences and Impact of Derailment	2011-2014	FP7 TRANSPORT			Y		Y	
DriveToTheFuture	Needs, wants and behaviour of 'Drivers' and automated vehicle users today and into the future	2019-2022	H2020-EU.3.4						Y
DTD SYSTEM 2	A disruptive innovation for the minimisation of railway maintenance costs (2)	2017-2019	H2020-EU.3.4.; H2020-EU.2.1.; H2020-EU.2.3.			Y			
DYNAFREIGHT	Innovative technical solutions for improved train DYNAmics and operation of longer FREIGHt Trains	2016-2018	Shift2Rail	Y			Y	Y	
DYNOTRAIN	Railway Vehicle Dynamics and Track Interactions Total Regulatory Acceptance for the Interoperable Network	2009-2013	FP7 SST					Y	
EATS	ETCS Advanced Testing and Smart Train Positioning System	2012-2016	FP7 TRANSPORT				Y		
ECOQUEST	Efficient Cooling Systems for QUieter Surface Transport	2009-2013	FP7 TRANSPORT		Y				
ECUC	Eddy CUrrent Brake Compatibility	2012-2015	FP7 TRANSPORT	Y					
E-FREIGHT	European e-freight capabilities for co-modal transport	2010-2013	FP7 TRANSPORT				Y	Y	Y
ELIPTIC	Electrification of Public Transport in Cities	2015-2018	H2020-EU.3.4		Y			Y	
E-LOBSTER	Electric LOsses Balancing through integrated STorage and power Electronics towards increased synergy between Railways and electricity distribution networks	2018-2021	H2020-EU.3.3		Y			Y	

EMULRADIO4RAIL	EMULATION OF RADIO ACCESS TECHNOLOGIES FOR RAILWAY COMMUNICATIONS	2018-2020	Shift2Rail				Y		
ERRAC ROAD MAP	ERRAC Road Map	2009-2012	FP7 TRANSPORT						Y
ERSAT GGC	ERTMS on SATELLITE Galileo Game Changer	2017-2019	H2020-EU.3.4.; H2020-EU.2.1.; H2020-EU.2.3.				Y		
ETALON	Energy harvesTing for signAlLing and cOmmunicatioN systems	2017-2020	Shift2Rail				Y		
EURAXLES	EURAXLES: Minimizing the risk of fatigue failure of railway axles	2010-2014	FP7 TRANSPORT	Y		Y			
EUREMCO	European Railway Electromagnetic Compatibility	2011-2014	FP7 TRANSPORT				Y	Y	
ExtenSive	Extending the attractiveness of transport for end user and extending IP4 to SaaS solutions.	2020-2023	Shift2Rail						Y
FAIR Stations	Future Secure and Accessible Rail Stations	2017-2019	Shift2Rail					Y	Y
FAST-TRACKS 2	Fast rAdio technologieS for uninterrupTed TRAin to traCKside communicationS (2)	2017-2019	H2020-EU.3.4.; H2020-EU.2.1.; H2020-EU.2.3.					Y	Y
FFL4E	Future Freight Loco for Europe	2016-2019	Shift2Rail	Y			Y	Y	
FINE 1	Future Improvement for Energy and Noise	2016-2019	Shift2Rail		Y				
FINE 2	Furthering Improvements in Integrated Mobility Management (I2M), Noise and Vibration, and Energy in Shift2Rail	2019-2022	Shift2Rail		Y		Y		
FLEX-RAIL	Paradigm shifts for railway - Technology uptake strategies for a lean, integrated and flexible railway system	2018-2021	Shift2Rail				Y		
FORESEE	Future proofing strategies FOr RESilient transport networks against Extreme Events	2018-2022	H2020-EU.3.4			Y			
FOSTER RAIL	Future Of Surface Transport Research Rail	2013-2016	FP7 TRANSPORT						Y
FOX	Forever Open infrastructure across (X) all transport modes	2015-2017	H2020-EU.3.4			Y		Y	Y
FR8HUB	Real-time information applications and energy efficient solutions for rail freight	2017-2020	Shift2Rail	Y			Y	Y	Y

FR8RAIL	Development of Functional Requirements for Sustainable and Attractive European Rail Freight	2016-2019	Shift2Rail	Y			Y	Y	
FR8RAIL II	Digitalization and Automation of Freight Rail	2018-2021	Shift2Rail	Y			Y	Y	
FR8RAIL III	Smart data-based assets and efficient rail freight operation	2019-2022	Shift2Rail	Y			Y	Y	
FR8RAIL IV	Use-centric rail freight innovation for Single European Railway Area.	2020-2023	Shift2Rail	Y			Y	Y	
FUNDRES	FUTURE UNIFIED DC RAILWAY ELECTRIFICATION SYSTEM	2019-2021	Shift2Rail		Y	Y		Y	
FUTURA	FUTUre RAil freight transport: cost-effective, safe, quiet and green!	2016-2018	H2020-EU.3.4.		Y				
GaLoROI	Galileo Localization for Railway Operation Innovation	2012-2014	FP7 TRANSPORT				Y		
GATE4RAIL	GNSS Automated Virtualized Test Environment for RAIL	2018-2020	Shift2Rail				Y		
Gearbodies	Innovative Technologies for Inspecting Carbodies and for Development of Running Gear	2020-2022	Shift2Rail	Y					
GoF4R	Governance of the Interoperability Framework for Rail and Intermodal Mobility	2016-2018	Shift2Rail					Y	Y
GoSAFE RAIL	Global Safety Management Framework for RAIL Operations	2016-2019	Shift2Rail			Y		Y	
GRAIL-2	GRAIL-2: GNSS-based ATP System for Railway Low Density Lines	2010-2013	FP7 TRANSPORT				Y		
Greenrail	Greenrail, innovative and sustainable railway sleepers: the greener solution for railway sector	2016-2018	H2020-EU.3.4.; H2020-EU.2.1.; H2020-EU.2.3.					Y	
HERMES	Development of Smart and Flexible Freight Wagons and Facilities for Improved Transport of Granular Multimaterials	2015-2018	H2020-EU.3.4	Y					
HYBRID-INFRA-RAIL	Deployment of hybrid systems for rail infrastructure to reduce energy consumption by 30%	2016-2019	CEF		Y			Y	
HYPERNEX	HYPERNEX: IGNITION OF THE EUROPEAN HYPERLOOP ECOSYSTEM	2020-2021	Shift2Rail						
IMPACT-1	Indicator Monitoring for a new railway PAradigm in seamlessly integrated Cross modal Transport chains - Phase 1	2016-2018	Shift2Rail				Y		

IMPACT-2	Indicator Monitoring for a new railway PAradigm in seamlessly integrated Cross modal Transport chains - Phase 2	2017-2022	Shift2Rail				Y		
IN2DREAMS	IN2DREAMS (INtelligent solutions 2ward the Development of Railway Energy and Asset Management Systems in Europe)	2017-2019	Shift2Rail		Y	Y		Y	
IN2RAIL	Innovative Intelligent Rail	2015-2018	Shift2Rail				Y		
IN2SMART	Intelligent Innovative Smart Maintenance of Assets by integRated Technologies	2016-2019	Shift2Rail			Y		Y	
IN2SMART2	Intelligent Innovative Smart Maintenance of Assets by integRated Technologies 2	2019-2022	Shift2Rail			Y		Y	
IN2STEMPO	Innovative Solutions in Future Stations, Energy Metering and Power Supply	2017-2022	Shift2Rail		Y	Y		Y	
IN2TRACK	Research into enhanced tracks, switches and structures	2016-2019	Shift2Rail		Y	Y		Y	
IN2TRACK2	Research into enhanced track and switch and crossing system 2	2018-2021	Shift2Rail		Y	Y		Y	
IN2TRACK3	IN2TRACK3	2020-2022	Shift2Rail		Y	Y		Y	
IN2ZONE	The Next Generation of Railway Transition Zones	2020-2023	Shift2Rail			Y		Y	
INESS	INtegrated European Signalling System	2008-2012	FP7 TRANSPORT				Y	Y	
INFRALERT	Linear Infrastructure Efficiency Improvement by Automated Learning and Optimised Predictive Maintenance Techniques	2015-2018	H2020-EU.3.4			Y		Y	
INNOWAG	INNOvative monitoring and predictive maintenance solutions on lightweight WAGon	2016-2019	Shift2Rail	Y		Y			
INTERAIL	Development of a Novel Integrated Inspection System for the Accurate Evaluation of the Structural Integrity of Rail Tracks	2009-2013	FP7 TRANSPORT			Y			
INTERMODEL EU	Simulation using Building Information Modeling Methodology of Multimodal, Multipurpose and Multiproduct Freight Railway Terminals Infrastructures.	2016-2019	H2020-EU.3.4						Y
IP4MaaS	Shift2Rail IP4 to support the deployment of Mobility as a Service	2020-2023	Shift2Rail					Y	

ISTIMES	Integrated System for Transport Infrastructures surveillance and Monitoring by Electromagnetic Sensing	2009-2012	FP7 SECURITY			Y			
IT2RAIL	Information Technologies for Shift to Rail	2015-2018	Shift2Rail					Y	Y
ITECCO Demo	Demonstration and market replication of Innofreight's innovative rail logistics equipment for the raw material supply of the steel industry	2016-2019	H2020-EU.3.4.; H2020-EU.2.1.; H2020-EU.2.3.	Y					
I-TOUR	i-TOUR: intelligent Transport system for Optimized URban trips	2010-2013	FP7 TRANSPORT						Y
LessThanWagonLoad	Development of "Less than Wagon Load" transport solutions in the Antwerp Chemical cluster	2017-2020	H2020-EU.3.4	Y					
LINX4RAIL	System architecture and Conceptual Data Model for railway, common data dictionary and global system modelling specifications	2019-2022	Shift2Rail					Y	
LINX4RAIL2	SYSTEM ARCHITECTURE AND CONCEPTUAL DATA MODEL FOR RAILWAY, COMMON DATA DICTIONARY AND GLOBAL SYSTEM MODELLING SPECIFICATIONS	2020-2023	Shift2Rail					Y	
LivingRAIL	Living in a sustainable world focused on electrified rail	2012-2015	FP7 TRANSPORT		Y				
LOCATE	Locomotive bOgie Condition mAinTEnance	2019-2021	Shift2Rail	Y			Y		
LONG LIFE BRIDGES	Long Life Bridges	2011-2015	FP7 PEOPLE			Y		Y	
M2O	MAke RAil The HOpe for protecting Nature 2 future OPERATION	2018-2020	Shift2Rail	Y			Y		
MaaSive	Passenger service platform specifications for an enhanced multi-modal transport eco-system including Mobility as a Service (MaaS)	2018-2021	Shift2Rail					Y	Y
MAINLINE	MAINtenance, renewaL and Improvement of rail transport iNfrastructure to reduce Economic and environmental impacts	2011-2014	FP7 TRANSPORT		Y			Y	
MARATHON	Make Rail The Hope for protecting Nature	2011-2014	FP7 TRANSPORT				Y	Y	
Mat4Rail	Mat4Rail	2017-2019	Shift2Rail	Y	Y		Y		
MAXBE	Interoperable Monitoring, Diagnosis and Maintenance Strategies for Axle Bearings	2012-2015	FP7 TRANSPORT	Y		Y			

MERLIN	Sustainable and intelligent management of energy for smarter railway systems in Europe: an integrated optimisation approach	2012-2015	FP7 SST		Y			Y	
MISTRAL	Communication Systems for Next-generation Railways	2016-2018	Shift2Rail				Y		
MOMIT	Multi-scale observation and monitoring of railway infrastructure threats	2017-2019	Shift2Rail			Y		Y	
MOVINGRAIL	MOving block and VIrtual coupling New Generations of RAIL signalling	2018-2020	Shift2Rail				Y		
MVDC-ERS	Flexible medium voltage DC electric railway systems	2018-2021	Shift2Rail	Y	Y			Y	
My-TRAC	My TRAvel Companion	2017-2020	Shift2Rail						Y
NEAR2050	Future challenges for the rail sector	2016-2018	Shift2Rail				Y		
NeTIRail-INFRA	Needs Tailored Interoperable Railway	2015-2018	H2020-EU.3.4.			Y	Y	Y	
NEXTGEAR	NEXT generation methods, concepts and solutions for the design of robust and sustainable running GEAR	2019-2021	Shift2Rail	Y	Y				
NGTC	Next Generation Train Control	2013-2017	FP7 TRANSPORT				Y		
ON-TIME	Optimal Networks for Train Integration Management across Europe	2011-2014	FP7 TRANSPORT				Y		
OPEUS	Modelling and strategies for the assessment and OPtimisation of Energy USage aspects of rail innovation	2016-2019	Shift2Rail		Y				
OPTIMA	cOmmunication Platform for TraffIc ManAgement demonstrator	2019-2023	Shift2Rail				Y		
OPTIRAIL	Development of a Smart Framework based on Knowledge to Support Infrastructure Maintenance Decisions in Railway Corridors	2012-2015	Shift2Rail			Y			
OptiYard	Optimised Real-time Yard and Network Management	2017-2019	Shift2Rail	Y			Y	Y	
OSIRIS	Optimal Strategy to Innovate and Reduce energy consumption In urban rail Systems	2012-2015	FP7 TRANSPORT	Y	Y				
PANTOTRAIN	PANTOgraph and catenary interaction: Total Regulatory Acceptance for the Interoperable Network	2009-2012	FP7 SST					Y	

PERFORMINGRAIL	PERformance-based Formal modelling and Optimal tRaffic Management for movING-block RAILway signalling	2020-2023	Shift2Rail				Y		
PINTA	IP1 Traction TD1 and Brakes TD5 - Phase 1	2016-2018	Shift2Rail	Y	Y		Y		
PINTA2	IP1 Traction TD1 and Brakes TD5 - Phase 2	2018-2020	Shift2Rail	Y	Y		Y		
PINTA3	IP1 Traction TD1– Phase 3 and HVAC TD8	2020-2023	Shift2Rail	Y	Y		Y		
PIVOT	Performance improvement for vehicles on track	2017-2019	Shift2Rail	Y	Y		Y		
PIVOT2	Performance Improvement for Vehicles on Track 2	2019-2022	Shift2Rail	Y	Y		Y		
PLASA	Smart Planning and Safety for a safer and more robust European railway sector	2016-2018	Shift2Rail				Y		
PLASA-2	Smart Planning and Virtual Certification	2018-2020	Shift2Rail				Y		
PMnIDEA	Predictive Maintenance employing Non-intrusive Inspection & Data Analysis	2009-2012	FP7 TRANSPORT			Y			
PROTECTRAIL	The Railway-Industry Partnership for Integrated Security of Rail Transport	2010-2014	FP7 SECURITY					Y	
PUBTRANS4ALL	Public Transportation - Accessibility for All	2009-2012	FP7 TRANSPORT						Y
QUIET-TRACK	Quiet Tracks for Sustainable Railway Infrastructures	2013-2016	FP7 TRANSPORT		Y				
RAAI	Whole Life Rail Axle Assessment and Improvement Using Ultrasonic Phased array and Corrosion Inspection Systems	2015-2018	H2020-EU.3.4.; H2020-EU.2.3.			Y			
RAILS	Roadmaps for A.I. integration in the raiL Sector	2019-2022	Shift2Rail				Y		
RECET4Rail	Reliable Energy and Cost Efficient Traction system for Railway	2020-2023	Shift2Rail	Y					
RESTRAIL	Reduction of Suicides and Trespasses on RAILway property	2011-2014	FP7 TRANSPORT					Y	
RIDE2RAIL	Travel Companion enhancements and RIDE-sharing services syncronised to RAIL and Public Transport	2019-2022	Shift2Rail					Y	Y

RIO	Railway Infrastructure Optimisation - Deployment of an innovative and technological rail infrastructure-vehicle interface system to ensure a low-carbon and energy-efficient freight transport system along the TEN-T Core Network Corridors	2014-2016	CEF		Y		Y		
RIVAS	Railway Induced Vibration Abatement Solutions	2011-2013	FP7 TRANSPORT		Y				
ROLL2RAIL	New Dependable Rolling Stock for a More Sustainable, Intelligent and Comfortable Rail Transport in Europe	2015-2017	Shift2Rail	Y	Y		Y		
RUN2RAIL	Innovative RUNning gear soluTiOns for new dependable, sustainable, intelligent and comfortable RAIL vehicles	2017-2019	Shift2Rail	Y	Y		Y		
SAFE4RAIL	SAFE architecture for Robust distributed Application Integration in roLling stock	2016-2018	Shift2Rail	Y			Y		
Safe4RAIL-2	Safe architecture for Robust distributed Application Integration in roLling stock 2	2018-2021	Shift2Rail	Y			Y		
Safe4RAIL-3	Advanced safety architecture and components for next generation TCMS in Railways	2020-2023	Shift2Rail	Y			Y		
SAFE-CTS	Efficient and cost-effective intermodal road-rail container freight system	2015-2017	H2020-EU.3.4.; H2020-EU.2.3.				Y		
SAFER-LC	SAFER Level Crossing by integrating and optimizing road-rail infrastructure management and design	2017-2020	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.; H2020-EU.2.3.					Y	
SAFTInspect	Ultrasonic inspection solution for railway crossing points	2017-2020	H2020-EU.3.4.; H2020-EU.2.1.; H2020-EU.2.3.			Y		Y	
SATLOC	Satellite based operation and management of local low traffic lines (SATLOC)	2012-2014	FP7 TRANSPORT				Y		
S-CODE	Switch and Crossing Optimal Design and Evaluation	2016-2019	Shift2Rail					Y	
SCORE	Score board of competitiveness of European transport manufacturing industries	2016-2018	H2020-EU.3.4	Y					
SDO-MET	Automatic Rail Safety Solution	2015-2017	H2020-EU.3.4.; H2020-EU.2.3.				Y		Y

SECRET	SECurity of Railways against Electromagnetic aTtacks	2012-2015	FP7 SECURITY					Y	
SECUREMETRO	Inherently SECURE blast resistant and fire safe METRO vehicles	2010-2013	FP7 TRANSPORT	Y					
Shift2MaaS	Shift2Rail IP4 enabling Mobility as a Service and seamless passenger experience	2018-2020	Shift2Rail					Y	Y
SIA	System for vehicle-infrastructure Interaction Assets health status monitoring	2018-2021	H2020-EU.3.4.; H2020-EU.2.1.			Y			
SILVARSTAR	SoIL Vibration and AuRalisation Software Tools for Application in Railways	2020-2022	Shift2Rail		Y			Y	
SMART	Smart Automation of Rail Transport	2016-2019	Shift2Rail	Y			Y	Y	
SMART RAIL	Smart Maintenance and Analysis of Transport Infrastructure	2011-2014	Shift2Rail		Y		Y	Y	
SMART2	Advanced integrated obstacle and track intrusion detection system for smart automation of rail transport	2019-2022	Shift2Rail	Y			Y	Y	
SMaRTE	Smart Maintenance and the Rail Traveller Experience	2017-2019	Shift2Rail			Y			
Smart-Rail	Smart Supply Chain Oriented Rail Freight Services - Smart-Rail	2015-2018	Shift2Rail	Y			Y	Y	
SolC-ITS	SOLRED C-ITS Monitoring Network	2016-2019	CEF						
SPECTRUM	Solutions and Processes to Enhance the Competitiveness of Transport by Rail in Unexploited Markets	2011-2015	FP7 TRANSPORT	Y			Y		
SPIDER PLUS	Sustainable Plan for Integrated Development through the European Rail Network Projecting Logistics & Mobility for Urban Spatial Design Evolution	2012-2015	FP7 TRANSPORT						Y
SPRINT	Semantics for PerfoRmant and scalable INteroperability of multimodal Transport	2018-2020	Shift2Rail					Y	Y
ST4RT	Semantic Transformations for Rail Transportation	2016-2018	Shift2Rail					Y	Y
STREAM	Smart Tools for Railway work safEty and performAnce iMprovement	2020-2023	Shift2Rail				Y		
SUNSET	SUstainable social Network SErvices for Transport	2011-2014	FP7 ICT						Y

SUSTRAIL	The sustainable freight railway: Designing the freight vehicle track system for higher delivered tonnage with improved availability at reduced cost	2011-2015	FP7 TRANSPORT	Y					
TAURO	Technologies for Autonomous Rail Operation	2020-2023	Shift2Rail			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.; H2020-EU.2.1.; H2020-EU.2.3.			Y			
TER4RAIL	Transversal Exploratory Research Activities for Railway	2018-2020	Shift2Rail				Y		
TIGER	Transit via Innovative Gateway concepts solving European Intermodal Rail needs	2009-2012	FP7 SST				Y		
TIGER DEMO	Trans-Rail Integrated Goods European-Express Routes Demonstrators	2011-2013	FP7 TRANSPORT				Y		
TRANSFEU	Transport Fire Safety Engineering in the European Union	2009-2012	FP7 SST	Y					
TRANSIT	Train pass-by noise source characterization and separation tools for cost-effective vehicle certification	2019-2022	Shift2Rail		Y				
Translate4Rail	Translation for breaking language barriers in the railway field	2019-2021	Shift2Rail				Y		Y
TRANSPHORM	Transport related Air Pollution and Health impacts - Integrated Methodologies for Assessing Particulate Matter	2010-2014	FP7 ENVIRONMENT		Y				
TREND	Test of Rolling Stock Electromagnetic Compatibility for cross-Domain interoperability	2011-2014	FP7 TRANSPORT					Y	
TT	Transforming Transport	2017-2019	H2020-EU.2.1				Y	Y	Y
USE-IT	Users, Safety, security and Energy In Transport Infrastructure	2015-2017	H2020-EU.3.4		Y				Y
VEL-WAGON	Versatile, Efficient and Longer Wagon for European Transportation	2010-2012	FP7 TRANSPORT	Y			Y		
VIRTUAL-FCS	VIRTUAL & physical platform for Fuel Cell System development	2020-2022	H2020-EU.3.4.		Y				
VITE	Virtualisation of the testing environment	2016-2018	H2020-EU.3.4.				Y	Y	
VIWAS	Viable Waggonload production Schemes	2012-2015	FP7 TRANSPORT				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.; H2020-EU.2.3.			Y			
WRIST	Innovative Welding Processes for New Rail Infrastructures	2015-2019	H2020-EU.3.4	Y					
X2Rail-1	Start-up activities for Advanced Signalling and Automation Systems	2016-2020	Shift2Rail				Y		
X2RAIL-2	Enhancing railway signalling systems based on train satellite positioning, on-board safe train integrity, formal methods approach and standard interfaces, enhancing Traffic Management System functions	2017-2020	Shift2Rail				Y		
X2Rail-3	Advanced Signalling, Automation and Communication System (IP2 and IP5) - Prototyping the future by means of capacity increase, autonomy and flexible communication	2018-2021	Shift2Rail				Y		
X2Rail-4	Advanced signalling and automation system - Completion of activities for enhanced automation systems, train integrity, traffic management evolution and smart object controllers	2019-2023	Shift2Rail				Y		
X2Rail-5	Completion of activities for Adaptable Communication, Moving Block, Fail safe Train Localisation (including satellite), Zero on site Testing, Formal Methods and Cyber Security	2020-2023	Shift2Rail				Y		
-	Demonstration study of infrastructure associated with an innovative LNG traction solution in railway operations	2017-2020	CEF		Y				

Annex 2. Scopus database regular expression analysis keywords

REGEX (documents retrieved in December 2020)

Rail transport sub-theme	Regular Expressions
Efficient stock design and manufacturing	TITLE-ABS-KEY(railway or rail) AND TITLE-ABS-KEY((stock or wagon or materials) and design) AND PUBYEAR > 2010 AND PUBYEAR < 2021 and DOCTYPE(ar)
Emissions and noise reduction	TITLE-ABS-KEY(railway or rail) AND TITLE-ABS-KEY("Noise reduction" or "energy management" or "energy saving" or "energy efficiency" or "alternative energy") AND PUBYEAR > 2010 AND PUBYEAR < 2021 and DOCTYPE(ar)
Track and stock maintenance	TITLE-ABS-KEY(railway or rail) AND TITLE-ABS-KEY("Track maintenance" or "rail maintenance" or "stock maintenance" or "wagon maintenance" or "infrastructure maintenance" or "predictive maintenance" or "condition monitoring") AND PUBYEAR > 2010 AND PUBYEAR < 2021 and DOCTYPE(ar)
Efficient rail operations	TITLE-ABS-KEY(railway or rail) AND TITLE-ABS-KEY("Connected technologies" or "EGNSS" or "ERTMS" or "GSM-R" or "signalling system" or "Automatic Train Protection" or "rail operation") AND PUBYEAR > 2010 AND PUBYEAR < 2021 and DOCTYPE(ar)
Infrastructure management	TITLE-ABS-KEY(railway or rail) AND TITLE-ABS-KEY("infrastructure management" or "Multimodal infrastructure" or "infrastructure safety" or "station design" or "catenary system" or "interoperability" or "electromagnetic compatibility" or "sleeper design") AND PUBYEAR > 2010 AND PUBYEAR < 2021 and DOCTYPE(ar)
ICT solutions to enhance the rail travel experience	TITLE-ABS-KEY(railway or rail) AND TITLE-ABS-KEY(ticketing or "multimodality" or "multimodal trip" or smartphone or accessibility) AND PUBYEAR > 2010 AND PUBYEAR < 2021 and DOCTYPE(ar)

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