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Research and innovation in connected and automated transport in Europe

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

Gkoumas, K., van Balen, M., Grosso, M., Marques Dos Santos, F.L., Tsakalidis, A., Ortega Hortelano, A., Haq, G., Pekár, F.

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Contact information
Name: Ferenc Pekár
Address: European Commission, Joint Research Centre, Vie E. Fermi 2749, I-21027, Ispra (VA) — Italy
Email: ferenc.pekar@ec.europa.eu
Tel.: +39 0332 783925

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Contents

Abstract

Adequate research and innovation (R&I) is paramount for the seamless testing, adoption and integration of connected and automated transport. This report provides a comprehensive analysis of R&I initiatives in Europe in this field. The assessment follows the methodology developed by the European Commission's Transport Research and Information Monitoring and Information System (TRIMIS). The report critically addresses research by thematic area and technologies, highlighting recent developments and future needs.

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Authors

Konstantinos Gkoumas, European Commission, Joint Research Centre

Mitchell van Balen, European Commission, Joint Research Centre

Monica Grosso, European Commission, Joint Research Centre

Fabio Marques Dos Santos, European Commission, Joint Research Centre

Anastasios Tsakalidis, European Commission, Joint Research Centre

Alejandro Ortega Hortelano, European Commission, Joint Research Centre

Gary Haq, European Commission, Joint Research Centre

Ferenc Pekár, European Commission, Joint Research Centre

Executive summary

The report presents a comprehensive analysis of research and innovation (R&I) in connected and automated transport in Europe in recent years, focusing on European Union (EU) funded projects. It identifies progress in several thematic fields and technologies, while highlighting the policy context and market activities in Europe and beyond.

Policy context

In May 2017, the European Commission (EC) adopted the Strategic Transport Research and Innovation Agenda (STRIA) as part of the 'Europe on the Move' package[1,2] which highlights key transport R&I areas and priorities for clean, connected and competitive mobility, under seven roadmaps. The STRIA roadmaps set out common priorities to support and speed up the research, innovation and deployment process leading to technology changes in transport that can act as enablers for future transport trends.

In May 2018, the EC revealed the third Mobility Package with the objective to allow citizens to benefit from safer traffic, less polluting vehicles and more advanced technological solutions, while supporting the competitiveness of the EU industry.[3] Particular focus is given to autonomous mobility that has the potential to make transport safer, more accessible, inclusive and sustainable.[4]

The STRIA roadmap for connected and automated transport (CAT) was updated in April 2019[5] and refines the research and innovation strategy for CAT initially developed within STRIA. Contrary to the legacy roadmap, the updated roadmap covers road, rail and waterborne transport, but not aviation, identifying initiatives supported by a number of actions to advance innovation and foster effective deployment. The roadmap does not cover aviation, considering the great advancement of the sector-specific strategic research planning in the topic. However, it identifies cross-modal links (including aviation) and possible innovation measures.

The roadmap covers R&I in eight distinct fields, namely: vehicles and infrastructure (physical and digital), communication, data processing, human factors, socioeconomic impacts, public acceptance and large scale actions for the deployment of CAT.

Even though some common challenges can be identified for all modes (in particular for what regards the technological development and the data transmission), some differences remain.

For example, for road transport it remains an open question when the diffusion of (fully) automated vehicles and the seamless co-existence with other vehicles will occur. However, when the penetration of connected and automated vehicles increases, it has the potential to disrupt the mobility scheme as we know it, and may have a major impact on road capacity and safety, especially in conjunction with other transport trends (e.g. shared mobility).[6]

In rail, air and waterborne transport, connectivity and automation already exist, and the challenge is to bring these concepts to the next level, having fully autonomous operations. These developments however do not involve travellers directly.

In light of numerous technological and human barriers for CAT to develop, this report supports the STRIA roadmap for CAT by assessing the state of play of research carried out in European Framework Programmes over the last eight years. The analysis identifies the current state of play and describes several developments that future R&I initiatives should consider.

The analysis is divided into five sub-themes: (i) on-board equipment; (ii) connectivity and safety; (iii) supporting infrastructure; (iv) socio-economic impacts and human factors; and (v) large scale testing. These sub-themes address challenges and findings across modes, including multi-modal transport. The analyses are integrated

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1 Commission staff working document — Towards clean, competitive and connected mobility: the contribution of transport research and innovation to the mobility package, SWD(2017) 223, Brussels.

2 Europe on the move - An agenda for a socially fair transition towards clean, competitive and connected mobility for all, COM(2017) 0283 final, Brussels.

3 Europe on the move - Sustainable Mobility for Europe: safe, connected, and clean COM/2018/293 final

4 Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee, The Committee Of The Regions, On the road to automated mobility: An EU strategy for mobility of the future COM/2018/283 final

5 https://trimis.ec.europa.eu/sites/default/files/roadmaps/stria_roadmap_2019-connected_and_automated_transport.pdf

6 Alonso Raposo, M. (Ed.), Ciuffo, B. (Ed.), Ardente, F., Aurambout, J-P., Baldini, G., Braun, R., Christidis, P., Christodoulou, A., Duboz, A., Felici, S., Ferragut, J., Georgakaki, A., Gkoumas , K., Grosso, M., Iglesias, M., Julea, A., Krause, J., Martens, B., Mathieux, F., Menzel, G., Mondello, S., Navajas Cawood, E., Pekár, F., Raileanu, I-C., Scholz, H., Tamba, M., Tsakalidis, A., van Balen, M., Vandecasteele, I., 2019, The future of road transport - Implications of automated, connected, low-carbon and shared mobility, EUR 29748 EN, Publications Office of the European Union, Luxembourg, doi: 10.2760/9247.

with findings from the Scopus database from 2005 to 2019, and European capacity analysis that covers the entire Seventh Framework Programme (FP7) and Horizon 2020 Framework Programme (H2020) timeframe (2007 to today).

The analysis is based on the European Commission's Transport Research and Innovation Monitoring and Information System (TRIMIS). Differently to the CAT roadmap structure, findings of this report are presented across all modes.

Main findings and conclusions

- Under FP7 and H2020 over € 1.5 billion has been invested in CAT research projects. This includes € 1 billion of EU funds and about € 500 million of own contributions by beneficiary organisations.
- Between 2007 and 2013, the FP7 programme funded 129 projects relevant to CAT technologies, with a total budget of € 704 million. Most of the projects were funded through the transport and ICT programmes of FP7. From 2014, projects were funded through the Horizon 2020 programme; 173 relevant projects have been identified in the TRIMIS database, with € 786 million of total funding. 73 % of this budget has been funded through the Smart, Green and Integrated programmes within the Societal Challenges section of H2020.
- A total of 1,526 unique organisations participated in FP7 and/or H2020 projects on CAT. Some organisations focus exclusively on CAT research in one mode of transport, whereas others conduct research across modes. Of the top 15 beneficiaries, 15 are active in road, 4 in rail, 5 in multimodal, 6 in air, and 2 in waterborne transport.
- Spending on CAT research under H2020 peaked in the beginning of 2018. Road transport received greatest interest, while waterborne transport receives the smallest amount of funds for CAT research amongst all modes.
- A text analysis of scientific research indicates that the number of publications in CAT is on the rise. *Connectivity and safety* and *on-board equipment* are the most present subthemes. The EU has the highest number of scientific publications overall, followed by the US and China, respectively. While China has the most publications in *Connectivity and safety*, Chinese research that addresses *on-board equipment* and *large scale testing* is limited. When compared to US publications, the EU has a larger number of publications on all topics, except for *large scale testing*. On a broader scale, the evolution of CAT related publications throughout 2005 to 2019 suggests that there has been a slow growth of publications until 2015, followed by a great increase. Scientific production on *socio-economic impacts* and *human factors* increased in 2018 and 2019.
- The technology analysis highlights clusters that are researched in FP programmes at different development phases. The concept of development phase as an indication of technology maturity has been consolidated in the TRIMIS assessment methodology and is used in this report.

In addition to the above contributions, more specific findings focus on the R&I of the five sub-themes.

On-board equipment sub-theme:

- The majority of projects covered by the analysis are at early stages of development, at basic research. Therefore, many of the projects have set the foundation for further development. The development of sensor technologies and on-board enablers is still necessary, as the majority of EU-funded projects under this sub-theme have yet to achieve large scale demonstration or implementation. Building upon these projects to validate technologies will enable technologies to develop beyond the initial research development phases, to reach demonstration and implementation. It remains, however, important to note that the private sector continues to invest in the demonstration of on-board technologies.
- Projects which address sensor performance and cost-effectiveness also continue to be important. Research projects which aim to reduce the costs of Light Detection and Ranging (LIDAR), or develop cost-effective alternatives with comparable performance, still require investment. In addition, research and investment in radar and camera-based systems, as well as the required processing software and hardware to accompany these systems, should continue. Requirements for sensors are likely to be different across different vehicle modes, due to performance, size and weight requirements, so these would require development in parallel with embedded knowledge sharing. Testing and validation of such systems also requires further research.
- As many projects are developing solutions to similar issues, there is greater scope to enhance collaboration. This is particularly applicable in the use of sensor technologies; sensor solutions are more reliable, can cope

with a range of weather or environmental conditions, and can be integrated with non-automotive applications. Similarly, projects to improve the human-machine interface could be based on latest developments in sensor capabilities, in automotive transport and other modes.

— As the majority of projects allocated to this sub-theme cover road and air transport, there is scope for research to focus on the development and implementation of on-board enablers for rail, waterborne and multimodal transport.

Connectivity and safety sub-theme:

— The majority of projects aiming to enhance connectivity and safety have focused on the early stages of technology development (i.e. basic research). As such, many of the projects under this sub-theme have set the foundation for further development. This holds particularly true for direct, cellular and hybrid communication technologies.

— There are few projects which focus on basic research into communication technologies themselves, and therefore, further research into this area could be valuable. Projects that show deeper integration between fully or partially automated vehicles and connectivity with infrastructure, other vehicles and other connected devices and users (V2X) should be encouraged, especially those can have a positive impact on safety.

Supporting infrastructure sub-theme:

— Projects on the supporting infrastructure sub-theme involve digital and physical infrastructure applications. The majority of projects under this sub-theme fall under the basic research development phase. Therefore, many of the projects have provided the basis for further development, and could benefit from follow up projects to test solutions and bring commercial propositions to market.

— Several of the projects examined display benefits to manufacturers and service providers, through developing digital and physical infrastructure innovations which enhance the efficiency of operations. User-centric projects are also researched in great volumes, aiming to deliver benefits to transport users through using transport data to enhance safety, reducing congestion and improving the accessibility of multimodal travel. With big data, artificial intelligence and human-machine interface applications still relatively new-to-market, further investments in their applications are still necessary to shift the average development phase from basic research to demonstration and implementation.

— Although the majority of projects focus on the development of digital infrastructure, some projects have researched the role of physical infrastructure in facilitating connected and automated transport. As under this sub-theme, there are relatively few projects that utilise data to improve physical, infrastructure design with connected vehicles in mind, this could be an area which requires further research.

Socio-economic impacts and human factors sub-theme:

— The majority of projects aiming to assess socio-economic benefits have focused so far on the early stages of technology development (i.e. basic research). Therefore, many of the projects have set the foundation for further development, with validation, demonstration and implementation at a larger scale still necessary. Under this sub-theme, the development of technologies for vulnerable road users and wider attempts to enhance the safety and welfare of passengers and crew, are all still relevant areas for research. Therefore, building upon projects that have since finished, will enable projects to develop beyond the initial research development phases, to reach demonstration and implementation.

— For several road transport projects, the research is based on the development of applications. Future research could aim to ensure that the latest state-of-the-art data sources and data processing techniques are used, as well as facilitating large scale trials and pilots. For other modes, research is more focused on developing a combination of hardware solutions and systems. This leaves testing and validation, as well as larger scale deployment, as sensible next steps.

— Several projects aim to enhance public and user acceptance of connected & automated vehicles. Therefore, there is great potential for these partners across projects to engage in knowledge sharing to maximise the resource invested in these projects and shift the projects from validation and demonstration to implementation.

Large scale testing sub-theme:

— The focus of projects allocated to the large scale testing sub-theme are diverse in nature, due to their categorisation by development phase rather than thematic area. Therefore, the vast majority of these projects have facilitated sufficient progress in technological development, with the implementation of tested technologies being the only remaining step to bring products to market.

- Despite the focus of some projects on non-road technologies, the vast majority of demonstration projects are focused on city and country-level applications, and relate to road transport. Therefore, there is greater scope to focus research on demonstrators for other transport modes, waterborne transport in particular.
- Safety and security are an underlying theme of the majority of demonstration projects. Therefore, it would be beneficial to build upon the research undertaken by past European-funded projects, as well as working alongside the private sector, to ensure that research is being optimised and that repetition of previous research projects is avoided, which does not lead to advances in the field.

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

Related and future JRC work

This report on research and innovation in connected and automated transport in Europe is one of the seven reports that support the implementation of the STRIA roadmaps. The TRIMIS team is consolidating and expanding the data repository to better assess R&I efforts of projects not funded by the EU or Member States. As part of this effort, information on patents and publications will be added. TRIMIS will continue to provide support to STRIA and, based on its research, provide recommendations to policymakers.

Quick guide

The report is structured as follows:

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

1 Introduction

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

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

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

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

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

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

As of November 2019, the updates of the roadmaps on "connected and automated transport" and "smart mobility and services" have been published (on April 2019 and October 2019, respectively), while two other ("infrastructure" and "low emission energy for transport") are in the process of being updated with the involvement of Member States (MS) and industry stakeholders.

The updated STRIA CAT roadmap[7] develops the research and innovation strategy for CAT initially developed within STRIA. The updated roadmap covers only road, rail and waterborne, and identifies initiatives supported by a number of actions to advance innovation and foster the effective deployment. The roadmap does not cover aviation, considering the great advancement of the sector-specific strategic research planning in the topic. However, it identifies cross-modal links (including aviation) and possible innovation measures.

The roadmap covers research and innovation R&I on vehicles and infrastructure (physical and digital), communication, data processing, and also addresses human factors, socioeconomic impacts, public acceptance and actions for the deployment of CAT.

Even though common challenges can be identified for all modes (in particular for what regards the technological development and the data transmission), these differ by mode.

For example, for road, the timeline for the diffusion of (fully) automated vehicles and the seamless co-existence with other vehicles is still unclear. The penetration of connected and automated vehicles has the potential to disrupt mobility as we know it, and may have a major impact on road capacity and safety, especially in conjunction with other transport trends (e.g. shared mobility).

In rail, air and waterborne transport, connectivity and automation already exist, the challenge is to bring these concepts to the next level to have fully autonomous operations. These developments, however, do not always directly involve travellers.

[7] https://trimis.ec.europa.eu/sites/default/files/roadmaps/stria_roadmap_2019-connected_and_automated_transport.pdf

The present report assesses R&I in CAT, based on TRIMIS. It provides a comprehensive analysis of selected 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 five key sub-themes, which largely cover the key areas of research being undertaken under this STRIA roadmap.

The sub-themes are:

1. On-board equipment: projects which involve the development, validation and implementation of on-board enablers and sensors.
2. Connectivity and safety: projects which involve vehicle-to-vehicle and vehicle-to-infrastructure technologies, as well as projects aiming to deliver security and safety improvements.
3. Supporting infrastructure: projects which involve the use of digital and physical infrastructure to support connected and automated transport.
4. Socio-economic impacts and human factors: focuses on projects, which deliver economic and social benefits to transport users and individuals working in the transport sector, as well as projects which elicit broader environmental benefits.
5. Largescale testing: projects which deliver largescale demonstrations of technologies.

The study aims to inform CAT stakeholders, including policy makers, regulators, transport service providers, and standardisation bodies, by providing insights into past and current research projects, researched technologies, level of funding and highlighting strengths and weaknesses of the field. The report can also assist the STRIA working group (WG) on CAT and other initiatives such as the Cooperative, connected and automated mobility (CCAM) platform, to better define R&I priorities.

2 Methodological background

This report reviews CAT related EU funded projects To do so, three actions were necessary:

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

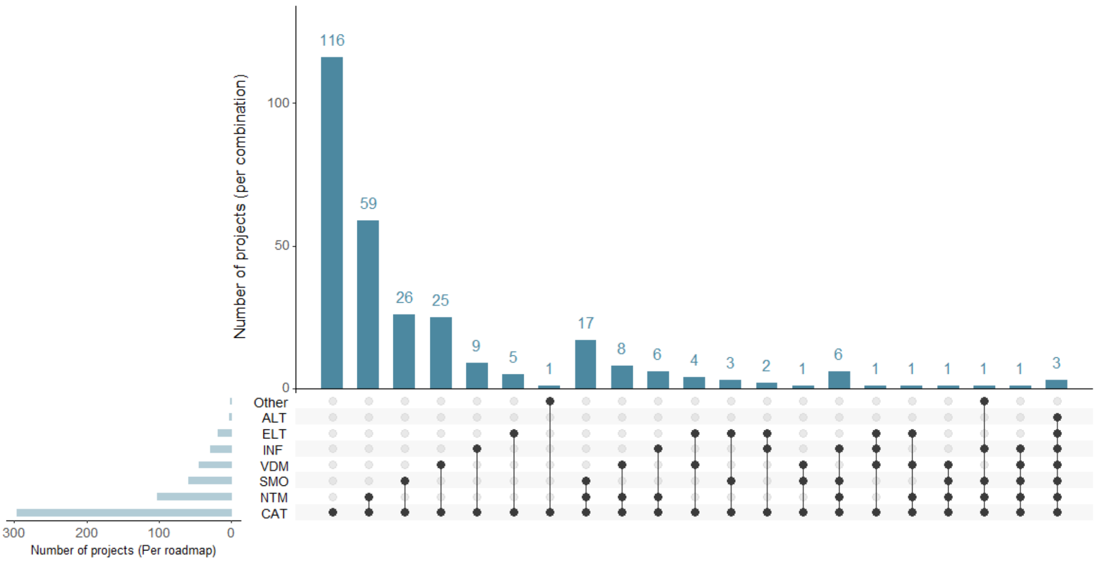
The following section provides a brief description of these steps together with guidance on how to interpret the results.

2.1 Database development and labelling

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

A key step in the assessment is to identify those projects that fall under the CAT roadmap, which was defined in the original STRIA roadmap. Based on this understanding, several transport specialists used machine learning algorithms and manual validation to label the projects.[8] Considering that many projects cover to some extent an aspect of CAT, only those projects with a considerable CAT research component in the project description were assigned to the CAT roadmap. A project can also be assigned to multiple roadmaps. Figure 1 provides an overview on the extent to which CAT projects overlap with other roadmaps, based on 240 FP7 and H2020 projects. It shows how often the keywords of each theme were detected (left horizontal bars) in the projects' objectives, and how often a certain combination of keywords occurred (vertical bars).

Figure 1. Overlap between connected and automated transport projects with other STRIA roadmaps



(*) Alternative Energy (ALT); Electrification (ELT); Vehicle Design & Manufacturing (VDM); Connected & Automated Transport (CAT); Smart Mobility (SMO), Network & Traffic Management (NTM), Infrastructure (INF).

Source: TRIMIS

As the figure suggests, some projects are crosscutting and include elements of other STRIA roadmaps. The overlaps should be considered when interpreting the results in this report.

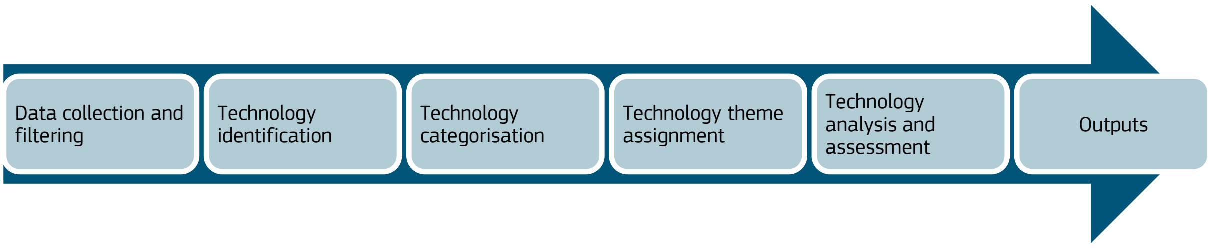
[8] The specialists also assessed the projects on several other variables, including the mode of transport and geographical focus of the project. Through discussions and interrater reliability assessments, the quality of the labelling is assured.

2.2 Identification and assessment of the technologies researched within FPs

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

The TRIMIS NETTs analysis focuses on technologies researched in European FP, specifically FP7 and H2020 projects in the TRIMIS database. Figure 2 provides an overview of the methodological steps undertaken.

Figure 2. Technology assessment methodological steps



Source: TRIMIS

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

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

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

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

When the technology list was established, a number of overarching technology themes 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 subsequently reduced to the minimum number of themes under which all technologies could still be logically placed. This process led to a total of 45 themes.

All projects were assessed on whether they focused on connected and automated transport. If so, the associated technologies and their themes were highlighted. The funds associated with each technology were determined by linking them with the total project budget. If multiple technologies were researched in the project, the budget allocated to the technology of interest was determined by dividing the project budget by the number of associated technologies. While this attribution approach is limited it is transparent and appropriate in the absence of technology-budget reports.

A set of metrics was then established to assess the 72 technologies identified within the CAT roadmap. These metrics indicate the potential for the technology to be taken forward to application.

2.3 Project assessment

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

Table 1 reports the sub-themes identified (left column), and the focus of each sub-theme (right column).

Table 1. Connected and automated transport sub-themes

Sub-theme	Sub-theme focus
On-board equipment	Projects which involve the development, validation and implementation of on-board enablers and sensors.
Connectivity and safety	Projects which involve vehicle-to-vehicle and vehicle-to-infrastructure technologies, as well as projects aiming to deliver security and safety improvements.
Supporting infrastructure	Projects which involve the use of digital and physical infrastructure to support connected and automated transport.
Socio-economic impacts and human factors	Projects which deliver or analyse economic and social benefits to transport users and individuals working in the transport sector, as well as projects which foster broader environmental benefits.
Largescale testing	Projects which deliver largescale demonstrations of technologies.

By adopting a clustering approach, it is possible to assess R&I findings focusing on specific areas of interest, identify missing areas, and compare developments. Annex 1 provides a table of all projects considered in this report, including their relevant sub-themes.

2.4 Research scope

Each chapter of this report addresses CAT R&I from a complementary perspective, with a research scope that is adjusted accordingly. Table 2 highlights the approaches used in various parts of the report to facilitate understanding and interpreting the results.

Table 2. 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, section 1 and 2: Quantitative project analysis	Statistical analysis	Covers FP7 and H2020 projects that commenced between 2007 and 2019
Chapter 5, section 3: Technology analysis	Statistical analysis	Covers FP7 and H2020 projects that developed a technology between 2007 and 2019
Chapter 5, section 4: Scientific output analysis	Bibliometric study	Covers publications within the SCOPUS database between 2005 and 2019
Chapter 6: Qualitative analysis	Project reviews	In-depth analysis of FP7, H2020 and CEF projects that commenced between 2012 and 2019

3 The state of connected and automated transport

CAT technologies will revolutionise the transport market in many ways, although in the short-term road transport is where most significant impacts are expected. For on-road applications, the definition of increasing driving automation levels is based on SAE J3016 standards[9] (see Table 3). Driver assistance (Levels 1 and 2) is incorporated in many new vehicles sold in Europe. Automated vehicles (Levels 3 and 4) are being tested and are expected to enter the market between 2020 and 2030. Fully automated vehicles (Level 5) are unlikely to start entering the market until 2035 at the earliest[10]. However, there is uncertainty about deployment levels for Level 5 autonomy, which is influenced by developments that could bring this forward or extend it towards 2050. This includes technological developments, such as sensors and processing capability, market conditions, regulatory and legal frameworks. By 2023, Level 3 and Level 4 automated functions are expected to account for approximately 0.8 % and 2.3 % respectively of the total vehicles sold globally and by 2030, the global market for privately owned automated vehicles (mostly Level 3 and Level 4) is expected to be US $60bn[11].

Table 3. Summary of levels of driving automation.

Level	Name	Sustained lateral and longitudinal vehicle motion control	Object and event detection and response	Dynamic driving task fallback	Operational design domain
Driver performs part or all of the Dynamic Driving Task					
0	No Driving Automation	Driver	Driver	Driver	n/a
1	Driver Assistance	Driver and System	Driver	Driver	Limited
2	Partial Driving Automation	System	Driver	Driver	Limited
Automated Driving System performs the entire Dynamic Driving Task					
3	Conditional Driving Automation	System	System	Fallback-ready user	Limited
4	High Driving Automation	System	System	System	Limited
5	Full Driving Automation	System	System	System	Unlimited

Source: SAE International

In parallel, road vehicles are becoming more connected, through the use of vehicle-to-infrastructure (V2I) or vehicle-to-vehicle (V2V) systems for communication and the Global Navigation Satellite Systems (GNSS) for positioning. In fact, automated and connected technologies are complementary, with connected and cooperative systems enabling more efficient and safe use of vehicles. Connected vehicles communicate with other vehicles (V2V), with infrastructure (V2I) and with other road users such as cyclists or pedestrians (V2X, vehicle-to-everything communication) using cellular or direct communication. To maximise benefits, it is essential that communication technologies are interoperable, compatible and safe. Vehicle connectivity applications being implemented and tested either use the DSRC-based standard 802.11p (ITS-G5 in the EU) or cellular V2X

[9] Accessible at: https://www.sae.org/standards/content/j3016_201806/

[10] ERTRAC (2019), Connected Automated Driving Roadmap, available at https://www.ertrac.org/uploads/documentsearch/id57/ERTRAC-CAD-Roadmap-2019.pdf

[11] Frost&Sullivan (2018), Global Autonomous Driving Market Outlook

technologies such as cellular connectivity or the Cellular vehicle-to-everything (C-V2X) technology being developed[12]. The industry is divided in terms of this technology choice.

One early example application of connected and automated driving support systems to road freight services is the possibility to form truck platoons by linking two or three trucks in a convoy. Truck platooning has potential to lead to fuel savings of up to 10 % for the lead truck and up to 17 % for the middle truck[13], and less road congestion, with a more efficient use of existing road capacity. An ACEA roadmap reveals that by 2023 it should be possible to drive across Europe on motorways with multi-brand truck platoons[14]. As part of the European Truck Platooning Challenge[15], a first cross-border truck platooning trial was completed in 2016 with semi-automated trucks[16].

High automation applications in public transport are being deployed in Europe in areas with low vehicle speed and/or dedicated infrastructure. New types of urban mobility vehicles could emerge because of further automation in this field, such as Personal Rapid Transport (PRT) for last mile trips or automated buses for in-city trips. While in some occasions automated shuttles (L4) have been in operation for more than 10 years already[17], according to an ERTRAC report, wider adoption of automated PRT and buses on dedicated roads are expected for 2020-2025 while operations on mixed traffic operations could follow as of 2025-2030,[18]. By 2030, buses with automated features are expected to take 30 % of bus rides globally, while the share of automated taxis may range up to 4 %[19].

With Europe accounting for 23 % of global motor vehicle production[20], the European industry will have a defining role in bringing disruptive CAT technologies into the market. Manufacturers and suppliers are allocating a significant part of their R&D efforts on connected and automated driving[21]. The overall impact on vehicle sales may be positive as reduced travel time costs[22] may lead to increased travel activity[23]. However, this effect could be offset by decreased vehicle ownership brought by new business models such as Mobility-as-a-Service (MaaS). In addition, revenue from sales linked to connected services may be offset by falling sales from legacy features (e.g. navigation, entertainment, and safety systems) and, thus, R&D costs may not be compensated through added value services[24]. Because of this, the overall economic impact on the automotive sector is still unclear. Other sectors such as electronics, software, telecommunication and data services are likely to experience significant growth.

The High-Level Group GEAR 2030 reveals that a number of legal, social and ethical barriers persist on the way to a full uptake of automated and connected road vehicles[25]. GEAR 2030 recommends the implementation of largescale open road testing and trials at EU level and the review of the EU type-approval framework regarding data storage requirements and vehicle certification.

Civil aviation has a long tradition of implementing automated technologies, from auto-pilot systems that automatically maintained the heading and altitude of the aircraft in the 1930's to today's smarter avionics systems integrated into the cockpit with an automation of most piloting functions. However, the current maximum level of automation in civil aviation is comparable to level 3 as defined in Table 3. Functions are automated, but the pilot remains the back up in case of automation failure. Increased levels of automation are not expected for passenger air services in the near future but developments for some applications of unmanned aircraft systems (drones) could move at a faster pace. In this field, automated operations could start with small drones in surveillance and monitoring applications beyond line of sight. While a few drones can already fly autonomously, this technology is still emerging. Improved system-failure responses, dynamic routing, and

[12] https://futurenetworks.ieee.org/tech-focus/june-2017/cellular-v2x
[13] https://www.nrel.gov/transportation/fleettest-platooning.html
[14] https://www.acea.be/uploads/publications/Platooning_roadmap.pdf
[15] https://www.eutruckplatooning.com
[16] https://www.acea.be/press-releases/article/first-cross-border-truck-platooning-trial-successfully-completed
[17] https://www.2getthere.eu/category/timeline/rivium
[18] ERTAC (2017), Automated Driving Roadmap, available at https://www.ertrac.org/uploads/documentsearch/id57/ERTRAC-CAD-Roadmap-2019.pdf
[19] Frost&Sullivan (2018), Global Autonomous Driving Market Outlook
[20] https://www.acea.be/statistics/tag/category/world-production
[21] https://www.acea.be/industry-topics/tag/category/connected-and-automated-driving
[22] Increased comfort and alternative uses of time while traveling decrease the value of time (i.e. the willingness to pay for travel time savings) and, hence, total cost of travel time perceived will be smaller
[23] JRC (2018), An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe
[24] pwc (2016), Connected car report 2016, Opportunities, risk, and turmoil on the road to autonomous vehicles
[25] GEAR 2030, High Level Group on the Competitiveness and Sustainable Growth of the Automotive Industry in the European Union (2017), Final report, Ensuring that Europe has the most competitive, innovative and sustainable automotive industry of the 2030s and beyond

handoffs between human and machine controllers are needed along with specific safety regulations to bring this technology into practice[26].

In maritime transport, autonomous and remote-controlled ships are being trialled but seafarers, for now, remain indispensable to safe shipping[27]. Maritime Autonomous Surface Ships (MASS) technology, however, is evolving faster than expected and may bring significant reductions in terms of shipping costs and CO_2 emissions[28]. Within the SVAN project, Rolls Royce and Finnish state-owned ferry operator Finferries successfully demonstrated in December 2018 the world's first fully remote and autonomous ferry operation in the archipelago south of the city of Turku, in Finland[29]. Forthcoming trials and potential commercial applications of autonomous or semi-autonomous operation are likely to be limited to short journeys, for example from one specific port to another, across a short distance. In parallel, automated mooring systems are being developed to enable fully autonomous shipping operations. The first commercial service with an autonomous container ship is expected by 2022[30]. Focusing on inland navigation, the Central Commission for the Navigation of the Rhine (CCNR) has defined 5 levels of automation[31] (Table 4).

Table 4. Automated navigation in inland waterways

	Level	Designation	Vessel command (steering, propulsion, wheelhouse, …)	Monitoring of and responding to navigational environment	Fallback performance of dynamic navigation tasks	Remote control
Boatmaster performs part or all of the dynamic navigation tasks	0	No automation	BM	BM	BM	No
	1	Steering assistance	S/BM	BM	BM	
	2	Partial automation	S/BM	S/BM	BM	Subject to context specific execution, remote control is possible
System performs the entire dynamic navigation tasks (when engaged)	3	Conditional automation	S	S	S/BM	
	4	High automation	S	S	S	
	5	Autonomous = full automation				

Abbreviations: S: System; BM: Boatmaster

Source: Central Commission for the Navigation of the Rhine

The application of CAT technologies in rail transport is especially suitable for metro systems, as they are mostly closed environments with restricted accessibility to third parties. The standard IEC 62290-1:2014 defines the different grades of automation for urban rail systems (Table 5). Fully automated driverless systems (grade 4) have been implemented in metro lines of Copenhagen and Barcelona, for example.

26 https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/commercial-drones-are-here-the-future-of-unmanned-aerial-systems
27 http://www.imo.org/en/MediaCentre/PressBriefings/Pages/22-MSC-100-special-session.aspx
28 IMO (2018), Technology Progression of Maritime Autonomous Surface Ships
29 https://www.rolls-royce.com/media/press-releases/2018/03-12-2018-rr-and-finferries-demonstrate-worlds-first-fully-autonomous-ferry.aspx
30 https://worldmaritimenews.com/archives/278488/worlds-1st-autonomous-ship-to-feature-macgregor-automated-mooring-system/
31 https://www.ccr-zkr.org/files/documents/AutomatisationNav/NoteAutomatisation_en.pdf

For interurban trains, under the umbrella of the European Rail Traffic Management Systems (ERTMS), advanced train control standards (ECTS) and communication standards (GSM-R) are increasingly deployed in the European rail network to ensure an interoperable ATP (Automatic Train Protection System). According to the European Rail Research Advisory Council's (ERRAC) Rail Vision 2050 report[32], the next generation of the ERTMS will include combinations of autonomous, intelligent and highly responsive vehicles that are able to communicate with each other and with the intelligent infrastructure. Autonomous rail operations would increase the capacity and flexibility of the rail transport system, guarantee an unprecedented level of safety and enable new types of mobility on rail, such as self-operated light pods/shuttles providing seamless interconnection across infrastructures.

Table 5. Grades of automation in urban rail systems

Grade of automation	Type of train operation	Setting train in motion	Stopping train	Door closure	Operation in event of disruption
1	ATP with driver	Driver	Driver	Driver	Driver
2	ATP and ATO with driver	Automatic	Automatic	Driver	Driver
3	Driverless	Automatic	Automatic	Train attendant	Train attendant
4	UTO	Automatic	Automatic	Automatic	Automatic

Source: International Electrotechnical Commission

[32] ERRAC (2017), RAIL 2050 VISION

4 Policy context

4.1 Connected and automated transport in European transport policy

The widespread application of CAT technologies can contribute to the efficiency and safety of the transport system. Moreover, CAT technologies may also facilitate the adoption of electromobility solutions, shared mobility concepts and optimised network management.

Focusing on road transport, while road safety in EU roads has improved over the past few decades, there has been almost no reduction in deaths since 2013[33], and it is unlikely that the EU will achieve its objective of a 50 % reduction in fatalities between 2010 and 2020[34]. CAT technologies have the potential to reduce road fatalities, since 90 % of road accidents come from human error[35]. However, new types of accidents might occur, although these are still hard to quantify or understand. In addition, by eliminating human reaction time in driving, vehicles could run at a steadier speed with a reduced safety distance between them. This would increase road capacity, reduce congestion, fuel consumption, and polluting air emissions including carbon dioxide. Another benefit of CAT technologies in road transport is increased accessibility by allowing specific mobility services for older people and the disabled.

However, CAT technologies could exacerbate transport externalities by increasing the demand for road transport. Travel time savings and increased comfort[36] delivered by a fully connected and automated transport system could stimulate additional road transport demand and increase trip lengths, as well as displace conventional public transport. This would lead to increased urban sprawl and congestion, without other policy actions. Therefore, active policies in this field should not only promote technologies and service innovations but also ensure that they contribute towards a low carbon, efficient and accessible transport systems (Alonso Raposo et al. 2019).

European policy in this field has focused on facilitating a common market for the development and largescale deployment of Connected and Automated Mobility (CAM) as part of the Digital Single Market (DSM) strategy[37]. Since the Declaration of Amsterdam in 2016, different advances have occurred in the field, such as the signature of the Letter of Intent in Rome on March 2017 where MS agreed to designate 5G corridors to enable cross-border testing of CAT technologies. The EU supports three 5G cross-border corridor projects for largescale testing of connected and automated mobility through the 5G Public Private Partnership, co-funded under H2020.

The Commission's Automated Mobility Strategy that was published as part of the mobility package of May 2018 (Europe on the Move III) sets the policy framework for the take-up of automated and connected mobility (European Commission, 2018a; 2018b). As part of this strategy, the EC will keep providing financial support to stimulate private investment in the development of technologies and infrastructure linked to automated and connected mobility.

The ITS Directive[38] {Directive 2010/40/EU} sets the legal framework for the deployment of Intelligent Transport Systems (ITS) in road transport to ensure a coordinated implementation of ITS in terms of the compatibility, interoperability and continuity of ITS solutions across the EU. The ITS Directive also sets a number of policy measures to support accessibility of EU-wide multimodal travel information for ITS users. In March 2019, the EC adopted new rules increasing the deployment of C-ITS in the form of a delegated act, which is based on the ITS Directive. The specifications establish the minimal legal requirements for interoperability between the various cooperative systems used (European Commission, 2019). In July 2019, the Council of the European Union adopted a decision to object to the proposal for Delegated Regulation on C-ITS (Council of the European Union, 2019).

Regarding other modes of transport, increased levels of connectivity and automation will contribute to the decarbonisation and safety goals of the respective modes by increasing the efficiency and safety in their operations. In this sense, the EC has promoted two large industrial initiatives, SESAR and ERTMS, related to

[33] https://ec.europa.eu/commission/news/road-safety-2019-apr-04_en

[34] https://europa.eu/rapid/press-release_MEMO-19-1990_en.htm

[35] GEAR 2030, High Level Group on the Competitiveness and Sustainable Growth of the Automotive Industry in the European Union (2017), Final report, Ensuring that Europe has the most competitive, innovative and sustainable automotive industry of the 2030s and beyond

[36] Increased comfort lowers the value of travel time and contributes to stimulate demand by decreasing the generalised cost of road transport

[37] https://ec.europa.eu/commission/sites/beta-political/files/euco-sibiu-a_digital_single_market.pdf

[38] Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport

improved network traffic management systems for air and rail transport, respectively, which will allow the adoption of automated and connected operations.

4.2 Connected and automated transport in European research programmes

Projects related to the CAT roadmap have been included in EU funding programmes for some years now. Using TRIMIS data, the different programmes that have funded CAT research have been identified. Tables 6-8 show these programmes, with the number of relevant projects and their funding level.

Between 2007 and 2013, the FP7 programme funded 129 projects relevant to CAT technologies, with a total budget of € 728 million (Table 6). Most of the projects were funded through the transport and ICT programmes of FP7.

From 2014, projects were funded through the H2020 programme; 167 relevant projects have been identified in the TRIMIS database, with €775 million of total budget (Table 7). 73 % of this budget has been funded through the Smart, Green and Integrated programmes within the Societal Challenges section of H2020.

Table 6. Numbers and values of CAT projects funded under FP7

Funding action	Number of projects	Total cost (million €)	EU contribution (million €)
FP7-AAT - Aeronautics and air transport	1	5.2	3.5
FP7-ICT - Information and Communication Technologies	51	349.4	226.9
FP7-NMP - Specific Programme "Cooperation": Nanosciences, Nanotechnologies, Materials and new Production Technologies	1	4.9	3.6
FP7-PEOPLE	1	3.9	3.9
FP7-RoK - Regions of Knowledge	1	2.7	2.3
FP7-SECURITY - Security	6	45.4	29.3
FP7-SME - FP7-SME - Specific Programme "Capacities": Research for the benefit of SMEs	1	1.5	1.2
FP7-SST - Sustainable Surface Transport	2	7.4	5.1
FP7-TRANSPORT - Transport (Including Aeronautics)	65	308.2	203.4
TOTAL	129	728.6	479.2

Source: TRIMIS

Table 7. Numbers and values of CAT projects funded under H2020

Funding action	Number of projects	Total cost (million €)	EU contribution (million €)
H2020-EU.1.3. - EXCELLENT SCIENCE - Marie Sklodowska-Curie Actions	1	0.2	0.2
H2020-EU.2.1. - INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies	16	206.5	82.5
H2020-EU.3.4. - Smart, Green and Integrated Transport	149	563.5	484.9
H2020-EU.3.7. - Secure societies - protecting freedom and security of Europe and its citizens	1	5.1	5.1
TOTAL	167	775.3	572.7

Source: TRIMIS

In addition to the two framework programmes, Table 8 presents the figures for projects that have been funded through other EU programmes. Programmes with projects finishing from 2017 onwards are included, together with the total number of completed projects and their budget within each programme. The Connecting Europe Facility (CEF) programme constitutes a significant funding source for CAT projects. In total, 22 projects have been identified with € 306 million funding from CEF. Beyond this, only one COST project has been identified in the TRIMIS database for CAT, but no funding information could be found.

Table 8. Numbers and values of CAT projects funded through other EU programmes

Funding action	Number of projects	Total cost (million €)	EU contribution (million €)
CEF - Connecting Europe Facility	22	306.9	129.5
COST - Co-operation in science and technology	1	n/a	n/a
TOTAL	23	306.9	129.5

Source: TRIMIS

4.3 Other European funding programmes

In addition to FP7 and H2020 funding programmes, there are several other European funding programmes that have supported CAT research projects. The Erasmus+ funding programme has supported training programmes related to CAT. For example, Steer2Career (2018-2021) aims to prepare truck drivers for upcoming shifts in the logistics sector due to increased automation. In addition, the Conference of European Directors of Roads (CEDR) funding programme finances projects such as Staple (2018-2020) and Mantra (2018-2020). Staple aims to provide a comprehensive review of the technological and non-technological aspects of connected and automated driving test sites, whilst Mantra aims to determine the key influences of automation on the core business of National Road Authorities (NRAs) in relation to road safety, traffic efficiency, the environment, customer service, maintenance and construction processes.

A short summary of the Co-operations in Science and Technology (COST) and CEF programmes, and relevant CAT projects, is provided below.

4.3.1 COST actions

The COST programme, which focuses on improving the effectiveness of funding from Member States through cross-border cooperation has funded CAT research. During FP7, COST enabled the interconnection of €5 billion in national research and technology projects, which equated to an investment of €250 million from COST.

WISE-ACT (2017-2021) is the only COST Action allocated to CAT in TRIMIS. WISE-ACT focuses on the wider implications of the deployment of autonomous vehicles, taking into account anticipated future mobility trends and implications on travel behaviour, such as car sharing, travel time use, residential location choice and broader social issues.

In addition, a number of additional COST Actions have some relevance to CAT, including WiNemO (2010-2014), IRACON (2016-2020), TransITS (2011-2015), Social Networks and Travel Behaviour (2014-2018) and ARTS (2012-2015).

WiNemO aimed to advance the state-of-the-art of networking aspects of scenarios integrating moving objects, ranging from personal use devices to sensors. The scientific results of the Action displayed promise in paving the way for further research. Among the most valuable results of the Action was the significant participation and coming together of researchers from different fields of wireless and mobile communications.

IRACON is developing an inclusive radio communications concept, defining the technologies to support wireless connectivity at any data rates. So far, the project has promoted the use of pan-European laboratory facilities and established networks for shared experimental research addressing Over-the-Air (OTA) testing, tracking and radio access, using a shared web platform.

TransITS aimed to engender and disseminate a new generation of transit assignment models tailored to ITS. The project gathered researchers, enabling knowledge exchange and research in the field of transit assignment models.

Social Networks and Travel Behaviour aimed to initiate a new collaboration framework for various EU research groups that develops a new transport paradigm based on ICT social networks and their subsequent travel behaviour in the urban environment. The project developed a joint discussion platform, which included seminars, thematic working groups, discussion sessions, workshops and the publishing of scientific results.

Finally, ARTS aimed to advance autonomic road transport support systems, through developing the foundation for the necessary technical infrastructure. The project established a knowledge base for developing autonomic ideas and techniques in largescale control systems, informing the research and development of autonomic systems for other application areas (i.e. energy management, computer network control).

4.3.2 CEF Projects

CEF is a key EU funding instrument, which aims to promote economic growth, job creation and competitiveness through targeted investment at the European level. CEF is divided into the energy, telecom and transport sectors, with the transport sector receiving €24.05 billion in the period 2014-2020[19].

CEF Transport focuses on cross-border projects and projects aimed at removing bottlenecks or bridging missing links in various sections of the TEN-T Core and Comprehensive Networks, as well as for horizontal priorities such as traffic management systems. CEF Transport also supports projects to enhance transport-related safety and projects that address the environmental impact of transport.

TRIMIS captures several CAT projects funded under CEF, some of which are explored in Section 6. These include Intercor (2016-2019), a project that aims to streamline C-ITS implementation in four Member States, bringing national initiatives together to establish a harmonised strategic specification. The project demonstrates largescale interoperable deployment of C-ITS, developed through participation in relevant C-ITS deployment platforms, such as C-Roads. Additional projects, CONCORDA and SCOOP@F, are discussed in Section 6.2.

4.3.3 Member State research and other initiatives

The 2019 STRIA CAT roadmap provides an overview of MS research on this topic, which includes projects from 14 MS on road (Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Latvia, Netherlands, Poland, Portugal, Spain, Sweden, United Kingdom) and 7 MS on rail (Austria, Belgium, France, Germany, The Netherlands, Poland, Spain). The roadmap highlights also industry driven and MS research for CAT waterborne.

For road and last mile delivery, the concept of living labs emerged in the last years. Living labs are a modern way of creating user-centred environments that enable innovation, co-creation and technology development. There are several initiatives in European cities sponsored by different institutes. In 2019 the JRC opened a pilot call for future mobility solutions in Ispra, encompassing different aspects (ad-hoc shared rides, door-to-door automated delivery, V2X, automated shuttle services, robo-taxi, clean vehicle solutions, etc)[39].

[39] https://ec.europa.eu/jrc/en/research-facility/living-labs-at-the-jrc/call-expression-interest-future-mobility-and-digital-energy-solutions

4.4 Connected and automated transport in non-European countries' policies

A study of the Society of Motor Manufacturers and Traders (SMMT)[40] reports that China and Japan are behind the US and some European countries such as the UK, Germany and the Netherlands in terms of enabling regulations, enabling infrastructure and market attractiveness. However, by 2025, China is expected to overtake North America and Europe in terms of the number of automated vehicles (Level 2 to 4) sold, whereas technology penetration wise, Europe is expected to lead the market for autonomous driving globally[41].

In the US, the Department of Transport's (US DOT) current ITS Strategic Plan 2015-2019, coordinated by the ITS Joint Program Office (JPO), is focused on two key priorities: Realizing Connected Vehicle Implementation and Advancing Automation. Most of the research activities of this programme are undertaken by different US DOT agencies in a coordinated way e.g. National Highway Traffic Safety Administration (NHTSA), Federal Motor Carrier Safety Administration (FMCSA), Federal Highway Administration (FHWA), and Federal Transit Administration (FTA). More recently, the document "Preparing for the Future of Transportation: Automated Vehicles 3.0 (AV 3.0)" advances US DOT's commitment to supporting the integration of automation into the broader multimodal surface transportation system. The Federal Government is responsible for regulating the safety performance of vehicles and vehicle equipment, as well as their commercial operation in interstate commerce, while states and local governments play the lead role in licensing drivers, establishing rules of the road, and formulating policy in tort liability and insurance. Nevada was the first state to authorise the operation of automated and connected vehicles in 2011. Since then, 21 other states have passed legislation related to automated and connected vehicles[42]. California, for example, has passed state level approval for driverless vehicle testing with no safety driver present. The United States Congress is discussing a bill for a Self-Drive Act, which would prevent states from enacting laws regarding the design, construction, or performance of highly automated vehicles or automated driving systems unless such laws enact standards identical to federal standards[43].

China released in October 2016 the "Technology Roadmap for Energy-Saving and New Energy Vehicles", which aims at reaching an installation rate for new vehicles of driving assist and partial automated driving of 50 % in 2020, 10 % to 20 % highly automated vehicles in 2025 and 10 % full automation in 2030. China has already adopted a plan to set up a preliminary standard system by 2020 and several roads in Beijing have been designated for autonomous driving tests. Other national test sites for connected and self-driving cars have been set in Shanghai and Chongqing. The explosive growth in China's automotive market has led to unsustainable levels of congestion and pollution. Autonomous and connected vehicles, especially when combined with shared and alternative fuelled operations, are seen as a potential solution to China's infrastructure challenges[44].

Japan's Cross-Ministerial Strategic Innovation Promotion Program (SIP) includes a research activity in connected and automated vehicles with a funding level of 3.37 billion yen in 2017[45]. Targets include the practical application of Level 2 systems in 2017, Level 3 in the early 2020s, and Level 4 sometime thereafter. As part of this, Japan has considered policies related to liabilities, driving licenses and cybersecurity laws. Different test sites are planned, for example the arterial roads around the Olympic games area in Tokyo, the express way around Tokyo, the JARI testing facilities, and the field operational test of automated bus driving in Okinawa.

Singapore has introduced an amendment to the Road Traffic Act, which now recognises that motor vehicles do not require human drivers, making it the first country to have policy in place to facilitate autonomous driving at a large scale. However, a qualified safety driver is still required to take control of the vehicle in an emergency. The Singapore Autonomous Vehicle Initiative (SAVI) was created as a joint partnership between the Land Transport Authority of Singapore (LTA) and the Agency for Science, Technology and Research (A*STAR) to provide a technical platform for industry partners and stakeholders to conduct R&D and test-bedding of CAT technology.

The South Korean government has designated autonomous vehicles as one of its top 13 Industrial Engine Projects. In 2017, South Korea's Ministry of Land, Infrastructure, and Transport allocated $24.5 million to

[40] SMMT (2019), Connected and autonomous vehicles. 2019 report, Winning the global race to market
[41] Frost&Sullivan (2018), Global Autonomous Driving Market Outlook
[42] http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx
[43] https://www.congress.gov/bill/115th-congress/house-bill/3388
[44] https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/how-china-will-help-fuel-the-revolution-in-autonomous-vehicles
[45] http://en.sip-adus.go.jp/sip/file/sip_en_2018_achievement_s.pdf

building AV infrastructure[46] and revised the Automobile Management Act, making it possible for self-driving vehicles to be tested on more than 300 km designated routes. Furthermore, South Korea has launched "K-City," a 360,000 square-meter pilot city, to test diverse prototypes of self-driving cars in real-world conditions using the 4G and 5G technology[47].

The Australian National Transport Commission has implemented the Automated Vehicle program, with the objective of endorsing end-to-end regulation to support the safe commercial deployment and operation of automated vehicles[48]. This includes important factors such as who is legally under the control of an automated vehicle, and also supported reforms that regulate government access to ICT infrastructure and vehicle data, as well as supporting driving laws that foresee the use of automated vehicles.

[46] Aida Joaquin Acosta (2018), What governments across the globe are doing to seize the benefits of autonomous vehicles, available at https://cyber.harvard.edu/sites/default/files/2018-07/2018-07_AVs03.pdf

[47] https://www.efe.com/efe/english/technology/south-korea-builds-fake-city-to-boost-self-driving-cars/50000267-4016079#

[48] https://www.ntc.gov.au/transport-reform/automated-vehicle-program

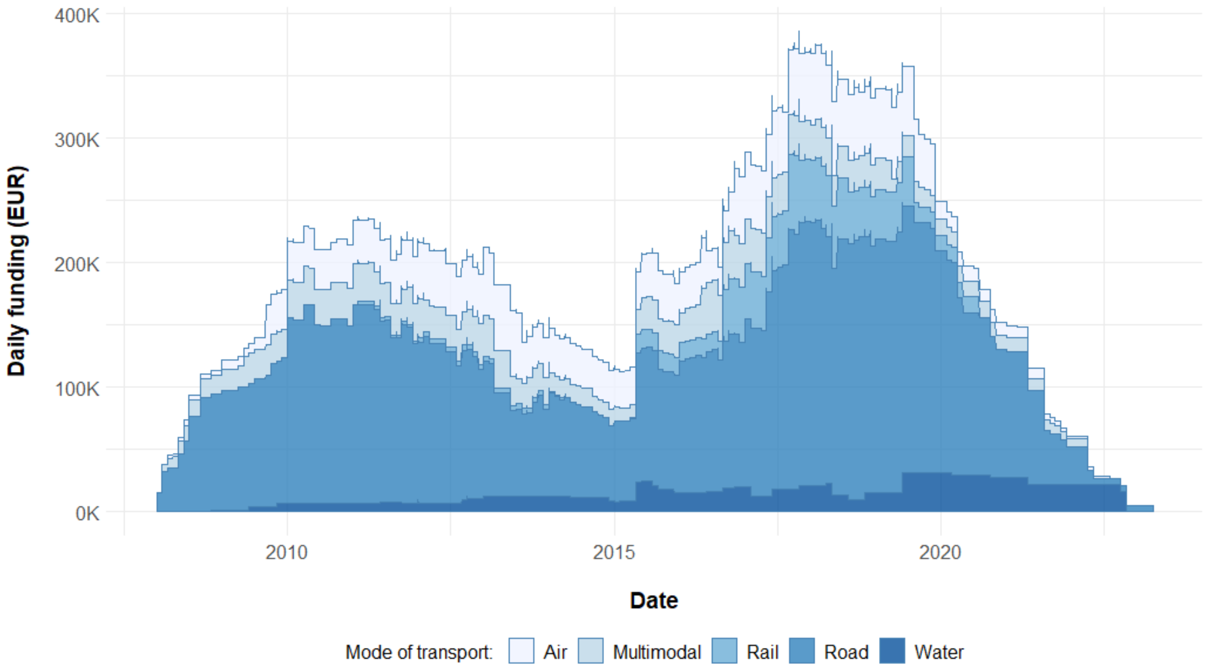
5 Quantitative assessment of CAT research

Under FP7 and H2020 over €1.5 billion has been invested in CAT research projects. This includes €1 billion of EU funds and about €500 million of own contributions by beneficiary organisations.

Figure 3 shows the aggregated funding statistics since 2008, assuming that project funds are spread equally over time. The figure shows an increase in funding under H2020 compared to FP7. Regardless of the framework programme, road transport research received the largest amount of funding. At the same time, funding of CAT in rail and water transport did grow under H2020.

The daily funding peaked in the first quarter of 2018 at approximately €370,000. A funding forecast is also provided, based on projects that were awarded by August 2019. As there are still open H2020 calls, it can be expected that the final funding will be higher.

Figure 3. Daily research funding by transport mode



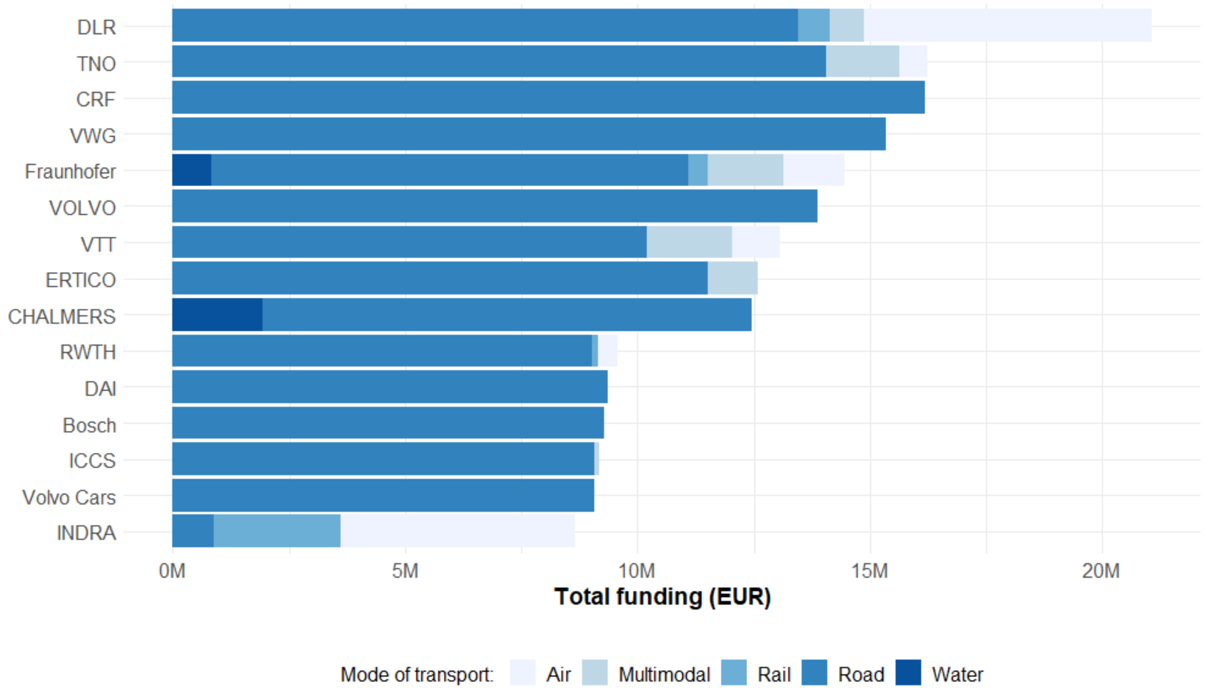
Source: TRIMIS

5.1 Geographical and organisation analysis

A total of 1,526 unique organisations participated in FP7 and/or H2020 projects on CAT. Figure 4 shows the top 15 beneficiaries with the total amount of funds received and their research focus in terms of transport mode.

Some organisations focus exclusively on CAT research in one mode of transport, whereas others conduct research across modes. Of the top 15 beneficiaries, 15 are active in road, four in rail, five in multimodal, six in air, and two in waterborne transport.

Figure 4. Top 15 CAT funding beneficiaries



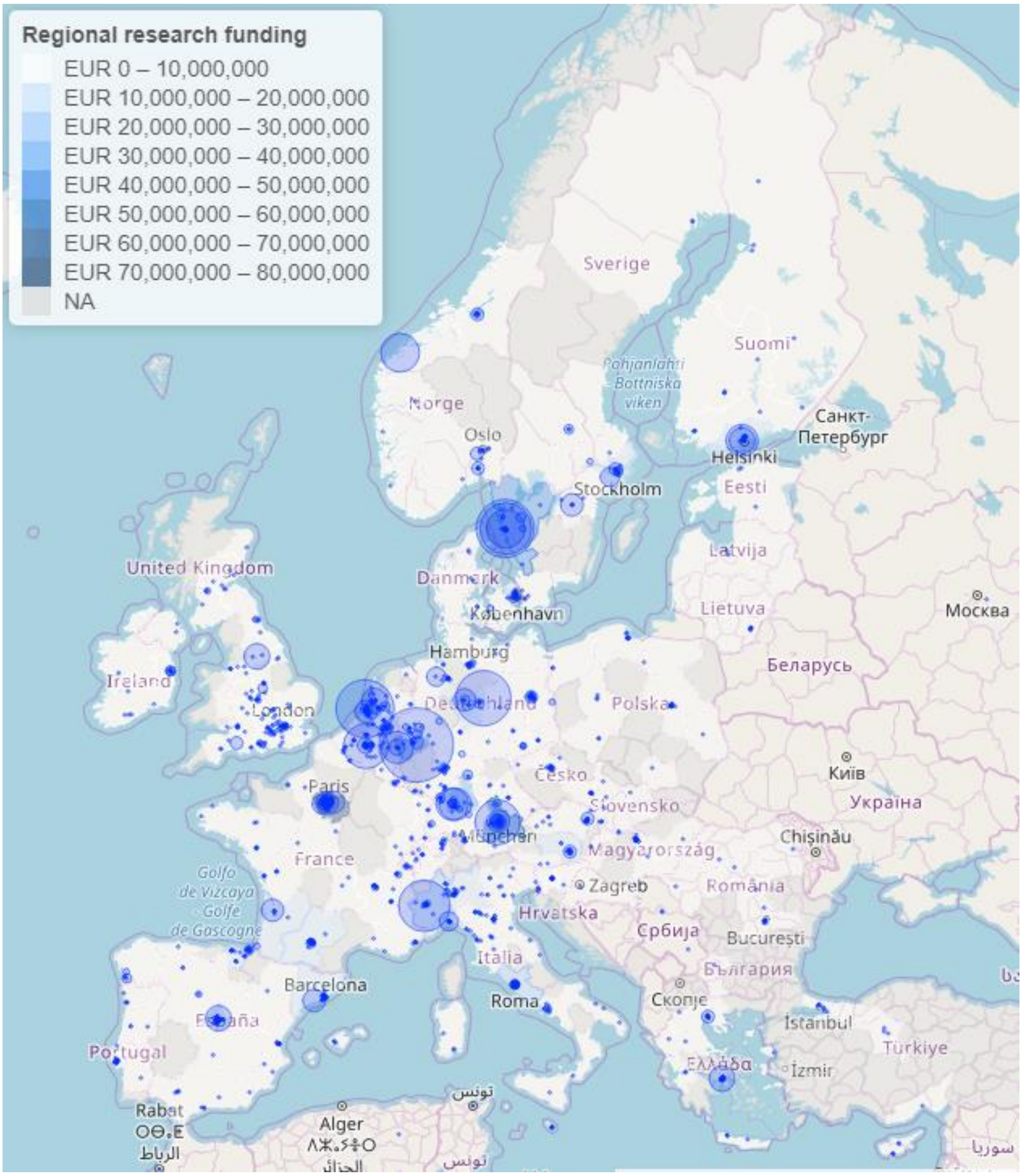
Source: TRIMIS

The top 15 beneficiaries received approximately € 190 million of funding, which is ~19 % of the total CAT funding budget. The funding concentration is therefore relatively low and funds are divided amongst a large number of organisations.

Figure 5 presents the geographical spread of CAT funds. Several beneficiaries in Germany, Italy and Sweden receive a large part of the funding, as indicated by the size of the circles. Most organisations are located in areas where large manufacturers are present, such as Turin (Italy), Munich (Germany) and Goteborg (Sweden). Organisations from the EU-13 receive a smaller share of the funds.

One remark is that the spending of research funds may happen in a different location than where a beneficiary is registered. This could be where pilot studies occur at different sites. However, the map does provide a reasonable approximation of where resources have been allocated.

Figure 5. Location of CAT funding beneficiaries

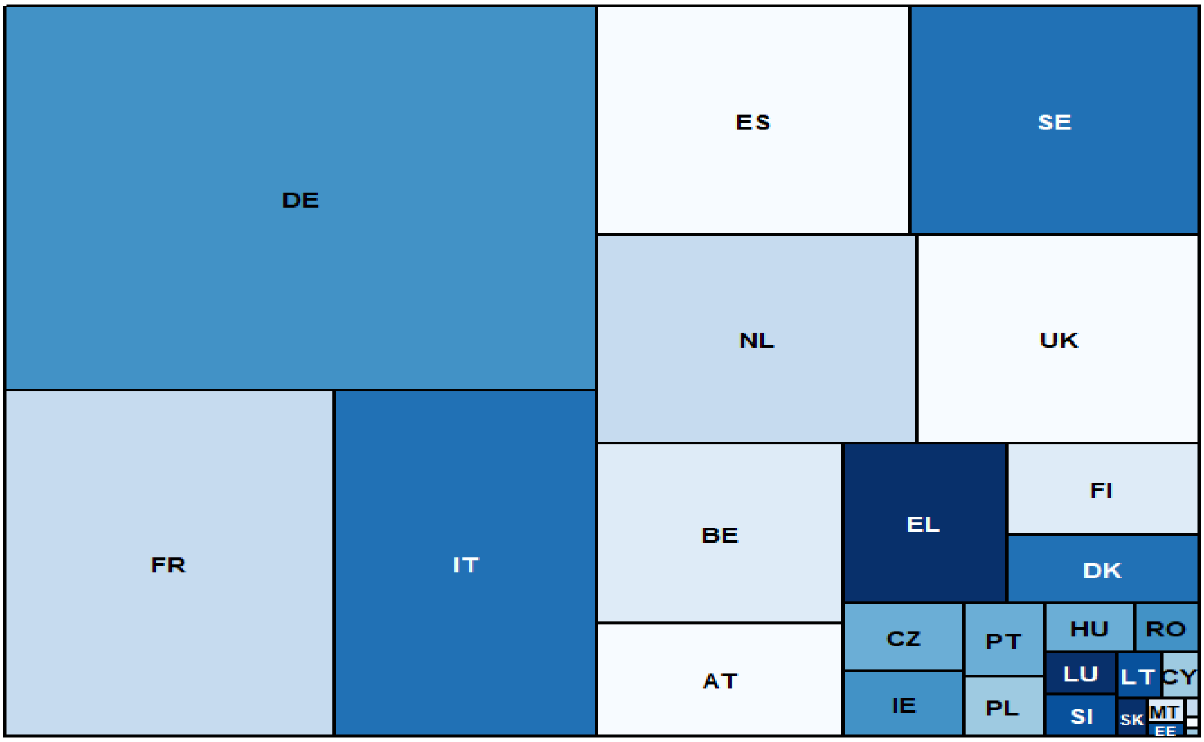


Source: TRIMIS

5.2 Member State analysis

An assessment of FP7 and H2020 CAT research in terms of funds received by MS, based on the beneficiaries' addresses, shows that Germany by far is the largest beneficiary in absolute terms, followed by France (see Figure 6). The imbalance that was noted in Figure 5 concerning the limited funding for organisation in EU-13 countries is shown here as well.

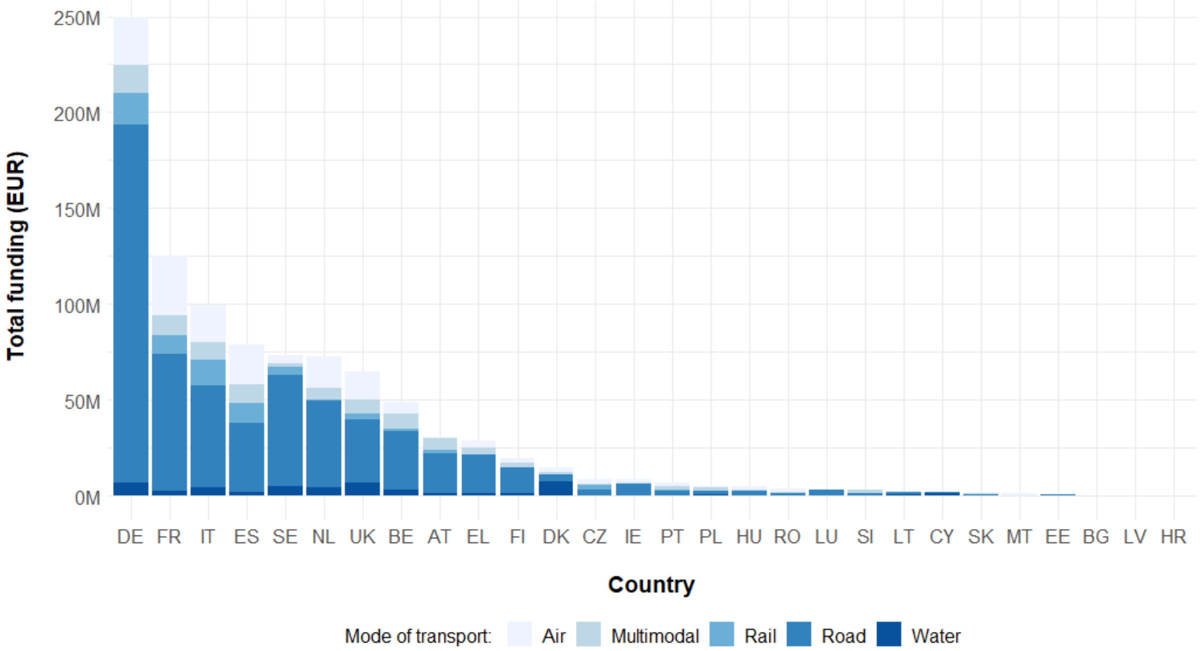
Figure 6. MS shares of CAT funding



Source: TRIMIS

Figure 7 provides a more detailed overview on CAT research funding, showing the total amount of funding received per MS, split by mode of transport. The figure also highlights some differences in modal focus. Germany, for instance shows a strong focus on road transport, whereas Denmark is relatively more active in waterborne transport research.

Figure 7. CAT funding by MS, including division between transport modes



Source: TRIMIS

In many projects a large number of organisations from various countries participate. These collaborations can be aggregated at a MS level to show which countries collaborate in the field of CAT research.

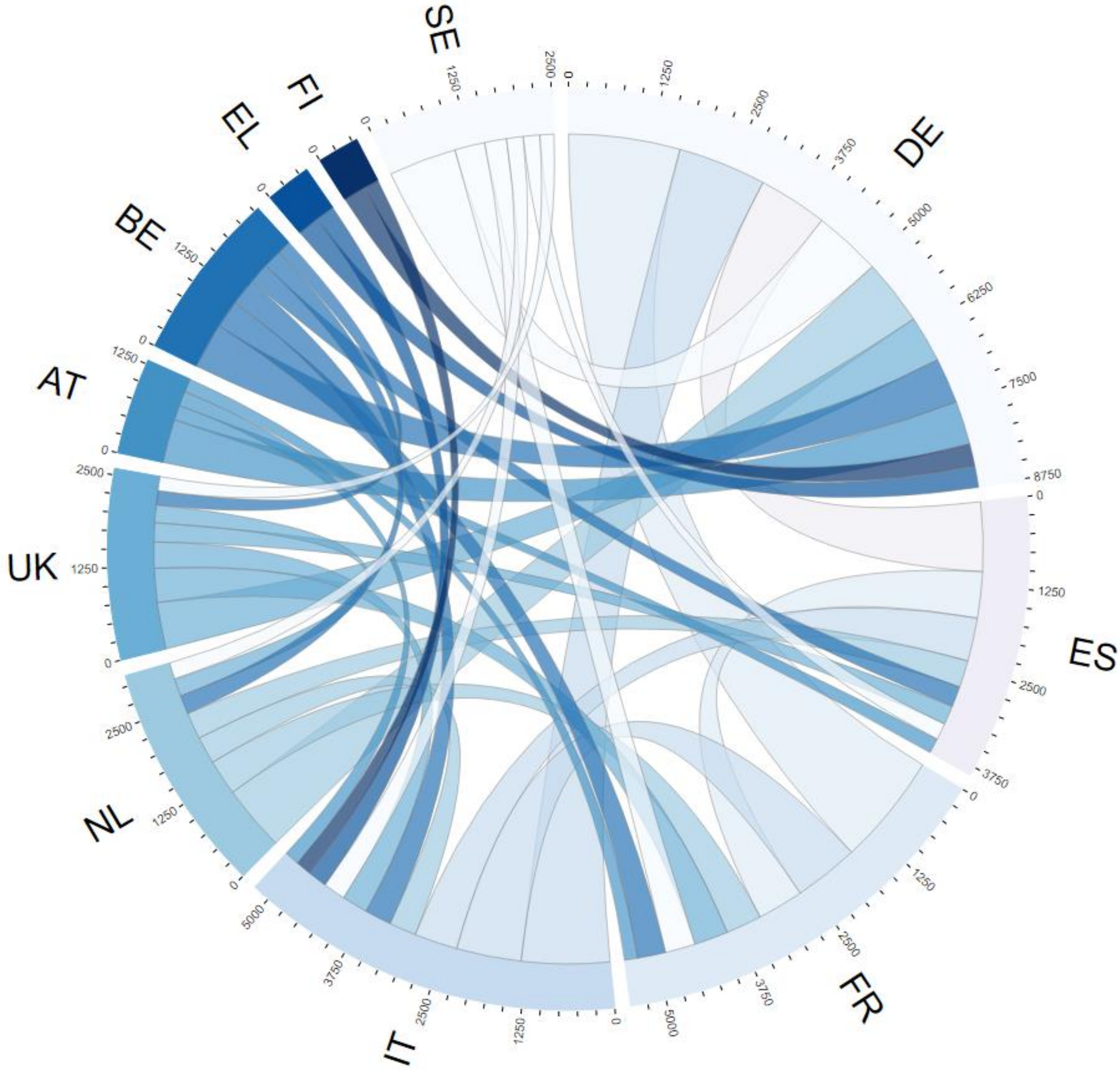
Figure 8 shows the most common links by highlighting those collaborations between organisations from MS that occurred at least 250 times. This means for instance that if in a project one Spanish and two Austrian organisations collaborate, the link between Austria and Spain gains a strength of two. These counts are accumulated for all projects. The colours are indicative of the country, whereas the width of the cords is indicative of the number of collaborations.

Eleven MS surpass the barrier of 250 organisational collaborations. Organisations from other MS also actively collaborate, but these ties are not visualised as they do not surpass the barrier. The analysis therefore focuses on absolute, rather than the normalised performance as was used in Figure 7.

Larger EU countries are most visible in this chart while Dutch organisations have strong relations with Germany and Italy in the field of CAT research.

Organisations from Belgium are also present in the collaboration network as illustrated by the presence of many Brussels based associations in the field of transport and technology.

Figure 8. Chord diagram on collaborations in FP7 and H2020 CAT projects by Member State

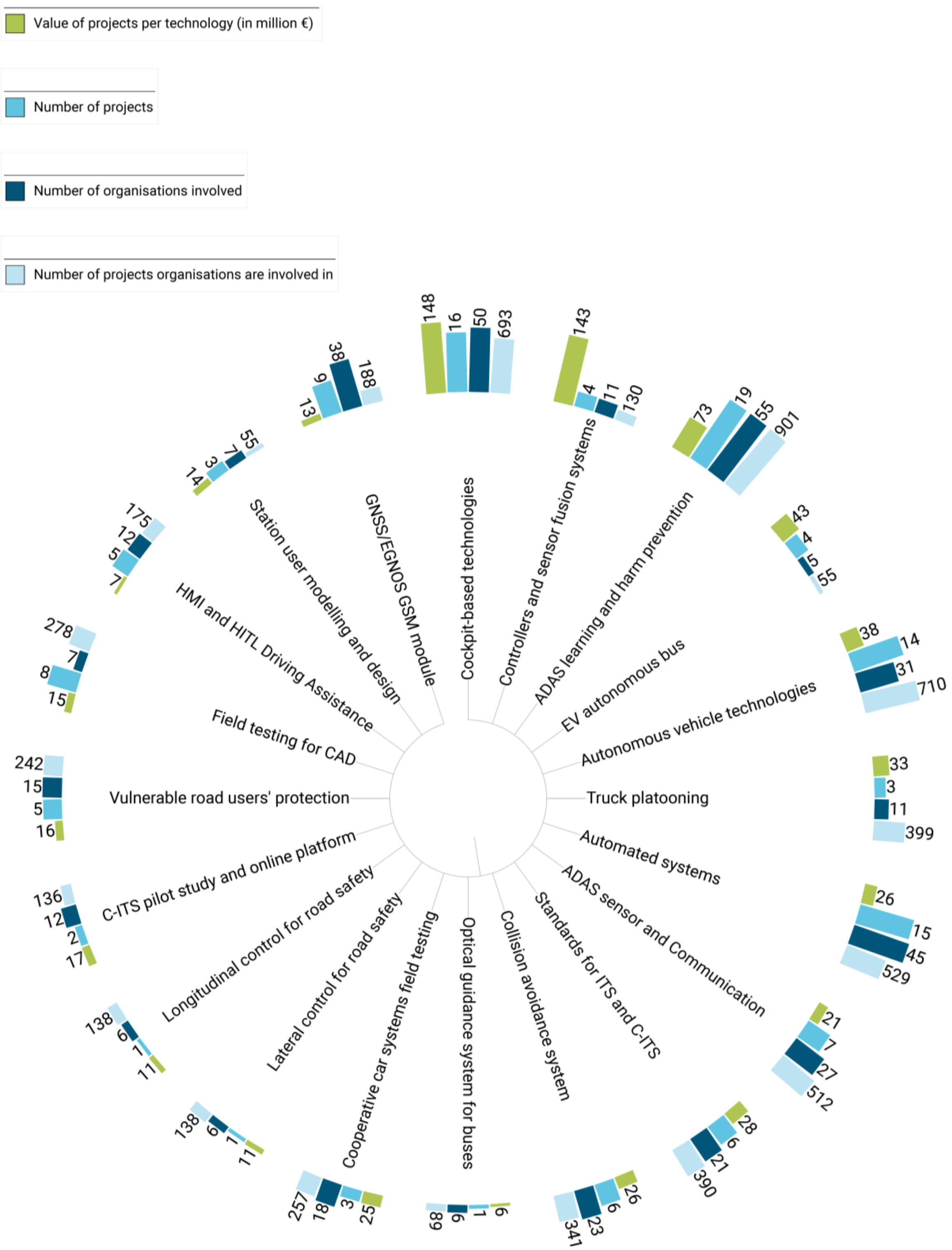


Source: TRIMIS

5.3 Technologies identified in the CAT roadmap

The analyses presented focus on the overall ‘top 20’ technologies identified for the CAT roadmap. The radial structure of Figure 9 highlights the key metrics of the ‘top 20’ technologies in terms of total funding.

Figure 9. Top 20 CAT technologies in FPs



Bars not in scale. Abbreviations: ADAS - Advanced driver-assistance systems; ITS - Intelligent Transport Systems; C-ITS - Cooperative Intelligent Transport Systems; CAD – Connected and Automated Driving; HMI – Human Machine Interface HITL - Hardware-in-the-Loop GNSS - Global Navigation Satellite System; EGNOS - European Geostationary Navigation Overlay Service; GSM - Global System for Mobile Communications.

Source: TRIMIS

Figure 9 is developed using the interactive tree of life (i-TOL), an open and freely available web-based tool for the display, manipulation and annotation of phylogenetic trees (Letunic and Bork 2019).

The metrics analysed in this case 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;
- "Number of organisations involved": the number of organisations that have been involved in projects that have researched the technology;
- "Number of projects organisations are involved in": the total number of projects that the organisations (identified as having been involved in projects researching the particular technology) have been involved in.

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

Among the top-20 technologies, all but three are linked to the road transport mode. *Cockpit-based technologies for improved pilot workflow* and *Collision avoidance system* are linked to aviation, while, *Station user modelling and design* is linked to railway transport.

The technology of *Cockpit-based technologies for improved pilot workflow* has received the highest funding, followed by research in *Controllers and sensor fusion systems*. The latter though, is researched only in four projects, most of them large scale (L3Pilot, NewControl and PRYSTINE).

Although the approach taken here has its limitations, the exercise of linking several technology metrics with organisational data 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.

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

The EC advised that EU-funded R&I projects should adopt the TRL scale in 2010; TRLs were then implemented for the H2020 programme (Heder, 2017), although in practice TRLs are not assigned to all H2020 projects. TRLs are based on a scale from 1 to 9, with 9 being the most mature technology.

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

Table 9 provides the description for each of the nine TRLs, as taken from Annex G of the H2020 work programme (2014-2015)[49] and the corresponding development phases used in TRIMIS.

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

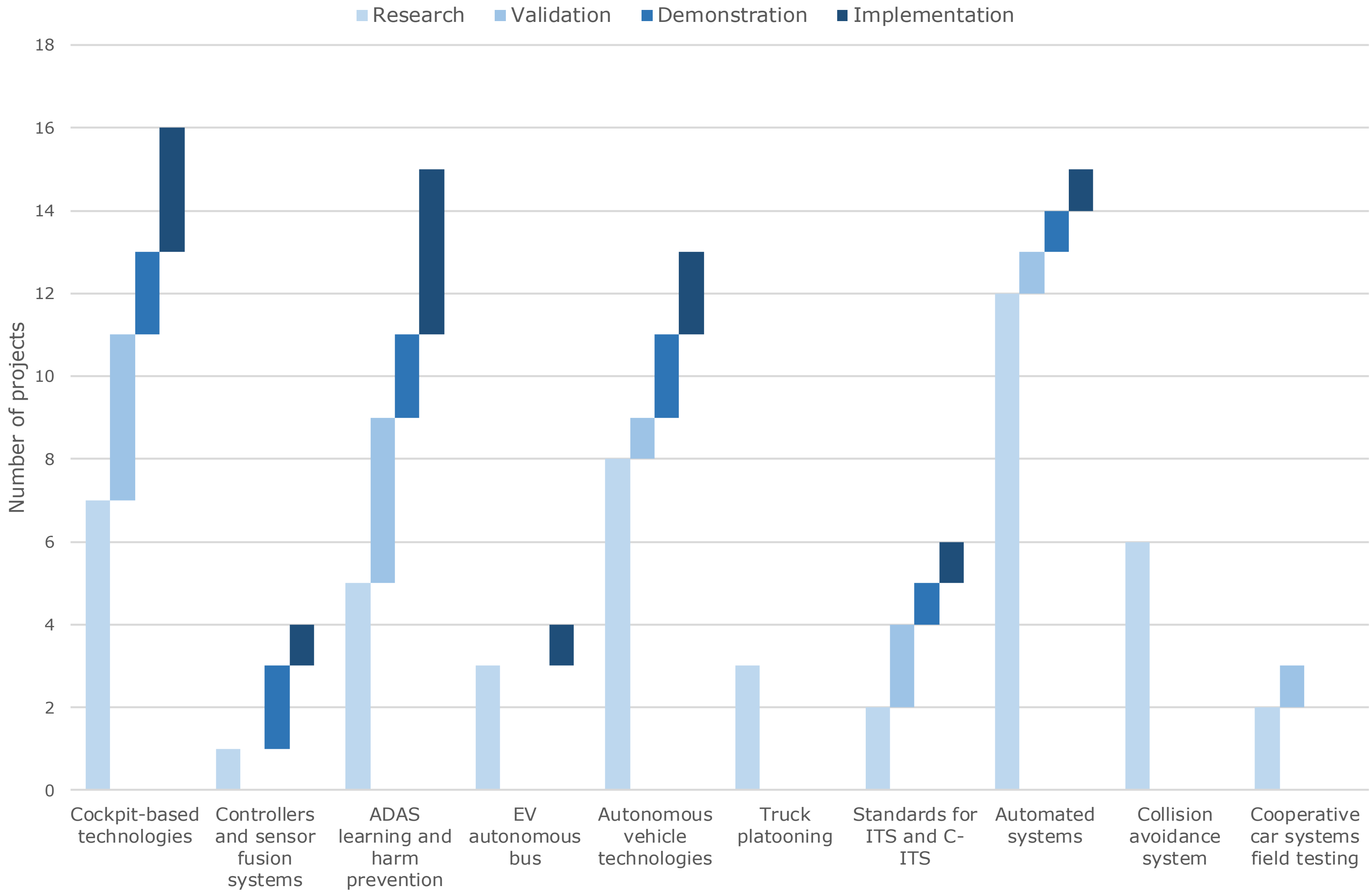
Table 9. Technology readiness levels (TRLs) and corresponding TRIMIS development phases

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

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

Figure 10 presents the development phases of the top ten researched CAT technologies in FPs. Five of the top ten technologies have been researched over the entire development phase in FP. *Truck platooning* and *collision avoidance systems* have been researched only at a research phase, something indicative of the (still) low maturity of these technologies. This holds also true for *cooperative car systems*, researched at research and validation phases. *Cockpit based technologies* (for aviation) and *ADAS learning and harm prevention systems* have been already researched also in implementation projects, while, *controllers and sensor fusion systems*, as noted earlier, are researched in largescale implementation projects, having reached a high maturity.

Figure 10. Development phases of the Top 10 researched CAT technologies in FPs



Source: TRIMIS

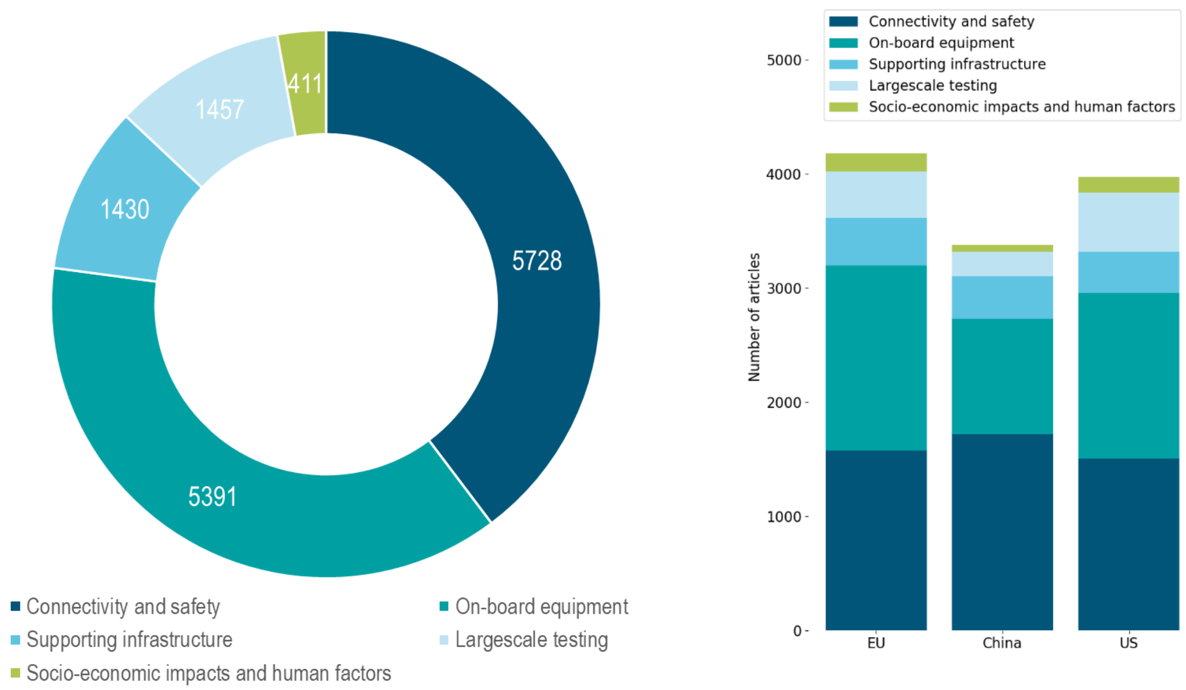
5.4 Analysis on scientific research

The Scopus citation database is a reference database for scientific research[50]. The following exercise aimed to determine the evolution of peer reviewed scientific publications in CAT research over the last 15 years, providing also a perspective beyond Europe.

For this exercise, a database of scientific journal papers related to CAT was used, and a number of keywords were assigned to the five topics previously mentioned. The complete list of regular expression (REGEX) used is reported in ANNEX 2. Findings show that there is international activity covering many aspects of automated transport research. EU, US and China are leaders in this field, with strong presence also from South Korea, Australia, Canada and Japan.

Figure 11 shows the number of published scientific journal articles for the five topics in the last 15 years (2005-2019), and also with division between the five topics and the top three publishing regions by affiliation. It is important to note that a single publication can be categorised in multiple subthemes and can also contain affiliations from more than one region. In this case, the publication is counted once for each subtheme and for each affiliation. Connectivity and safety and on-board equipment are the most present subthemes. Moreover, the EU has the highest number of scientific publications, followed by the US and China, respectively. Even though China has the most publications in connectivity and safety, their scientific production in on-board equipment and largescale testing is limited. When compared to US publications, EU has a larger number of publications on all topics, except for largescale testing.

Figure 11. Overview of connected and automated transportation publications in the period 2005-2019



Source: TRIMIS elaborations based on Scopus data

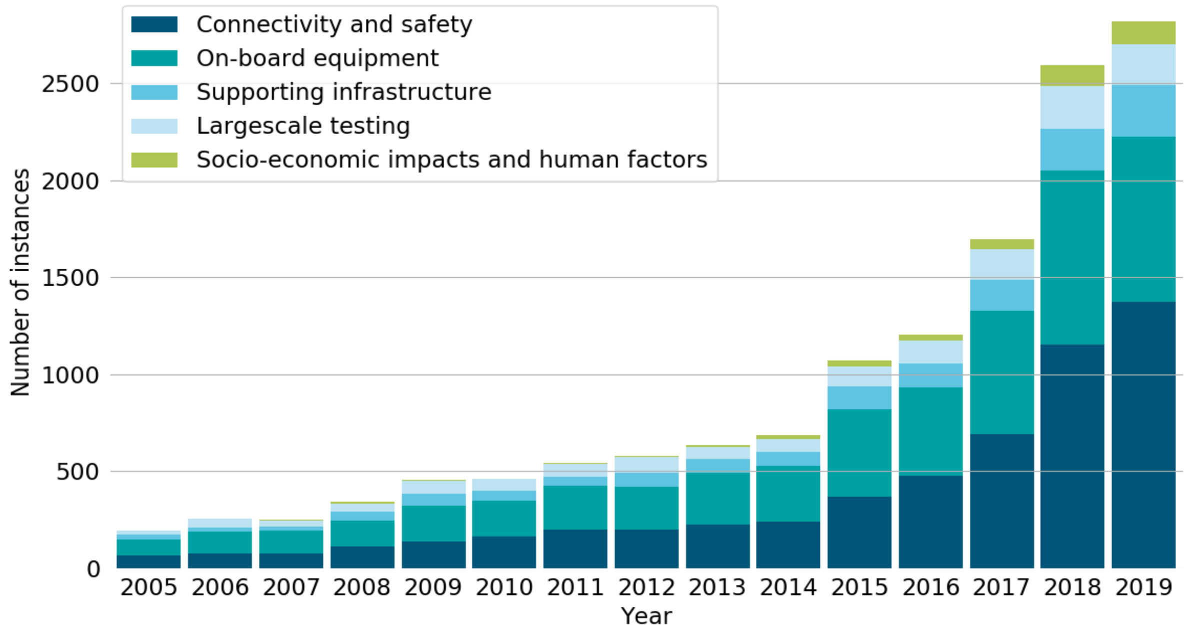
Figure 12 shows the evolution of automated transport publications from 2005 to 2019. It suggests that there has been a slow growth of publications until 2015, after which there is a great increase. Scientific production on socio-economic impacts and human factors is increased in 2018 and 2019. In order to better analyse the evolution of each subtheme, the percentage of the total number of articles for the subthemes is shown in Figure 13. It can be seen that on-board equipment publications have the greatest share of scientific publications until 2015, when connectivity and safety begins to have a greater share.

To better understand the evolution of publications for the three regions, the progression of scientific papers from 2015 to 2019 for the five subthemes was analysed.

[50] www.scopus.com

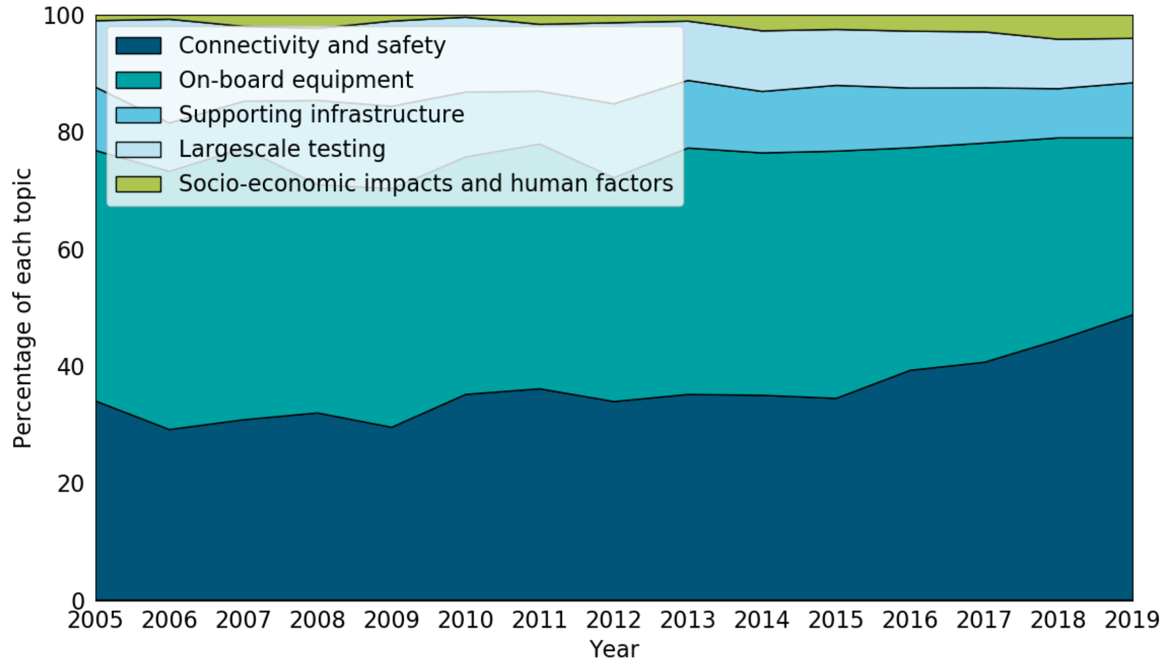
Figure 14 and Figure 15 show the number of publications for all the subthemes and for the EU, China and US. For Connectivity and safety, China has the lowest number of publications in 2015 but this increases by 2019, where China as the highest number. The output for on-board equipment, supporting infrastructure and largescale testing show a similar trend, with the US and EU with similar numbers of publications, with China having significant growth, especially on supporting infrastructure. Finally, the scientific production on socio-economic impacts and human factors is greater in the EU and US, with limited Chinese output until 2018.

Figure 12. CAT publications evolution in the period 2005-2019



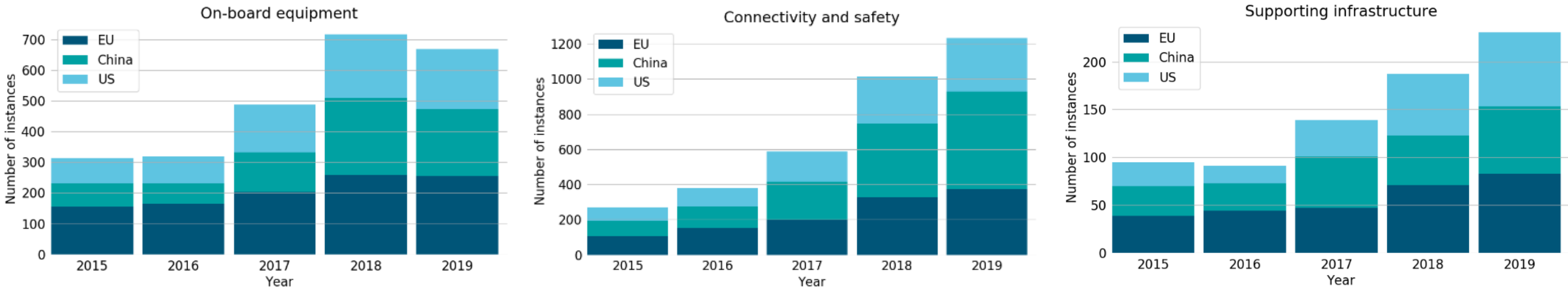
Source: TRIMIS elaborations based on Scopus

Figure 13. CAT publications sub-theme share in the period 2005-2019



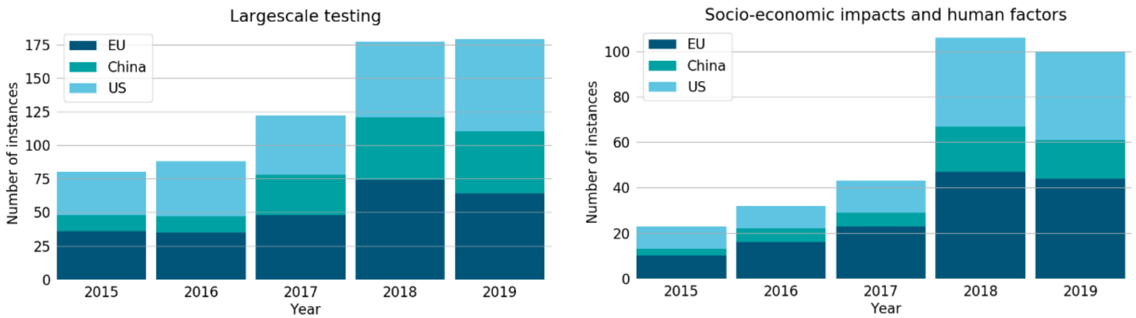
Source: TRIMIS elaborations based on Scopus

Figure 14. Number of publications for the EU, China and US (on-board equipment, connectivity and safety and supporting infrastructure sub-themes)



Source: TRIMIS elaborations based on Scopus

Figure 15. Number of publications for the EU, China and US (largescale testing and socio-economic impacts and human factors sub-themes)



Source: TRIMIS elaborations based on Scopus

6 Research and Innovation assessment

This section analyses R&I CAT projects under five key sub-themes, which cover the main areas of research being undertaken under this STRIA roadmap. The analysis provides an overview of research results and subsequent implications for future research and policy development. The sub-themes are:

1. On-board equipment. This sub-theme focuses on projects which involve the development, validation and implementation of on-board enablers and sensors. This sub-theme covers projects across all transport modes, including advanced driver-assistance systems (ADAS), on-board equipment for navigation and innovative satellite technologies. The sub-theme also includes projects which use sensors for environmental and operational monitoring.

2. Connectivity and safety. This sub-theme focuses on projects which involve vehicle-to-vehicle and vehicle-to-infrastructure technologies, as well as projects aiming to deliver security and safety improvements. This includes projects which aim to develop and validate traffic management systems, as well as projects which deliver network information. The sub-theme also involves communication and satellite technologies and therefore, shares some overlaps with the first sub-theme.

3. Supporting infrastructure. This sub-theme focuses on projects which involve the use of digital and physical infrastructure to support connected and automated transport. This includes projects which develop and implement big data and artificial intelligence applications. This includes AI-based autonomous flight control and the use of AI to enable vehicle predictive maintenance. In addition, this sub-theme also includes projects which involve the development of physical infrastructure, such as developing integrated solutions for accessible train stations.

4. Socio-economic impacts and human factors. This sub-theme focuses on projects which deliver economic and social benefits to transport users and individuals working in the transport sector, as well as projects which foster broader environmental benefits. This involves projects which aim to enhance the user and public acceptance of connected and automated transport. In addition, the sub-theme also covers projects which respond to the issues facing the transport sector workforce, such as the development of crew-centred operations. Due to the focus on societal benefits, there is some overlap with the safety aspect of the second sub-theme.

5. Largescale testing. This sub-theme focuses on projects which deliver largescale demonstrations of technologies. This involves projects which conduct pilot studies and broader multi-city demonstrations, to test for wider deployment of technologies. This includes primarily road-based projects, which involve demonstrations across multiple cities, for both passenger and freight transport. Many of the projects assigned to this sub-theme also align to additional sub-themes, due to the nature of the technologies being tested.

Each sub-theme involves the application of smart solutions to enhance CAT and are interlinked to the sub-themes and their respective objectives. It is also important to note that all of the sub-themes cover multiple modes of transport. However, road transport comprises the greatest proportion of projects (50 %), which reflects the current state-of-play of wider CAT research.

As noted in the policy and market context, the projects covered in the analysis are primarily completed projects. Therefore, the technologies developed by the projects and examined in the analysis are likely to be outdated, due to the speed of technological innovation and the continual progress being made in the field of CAT. However, the outcomes of these projects and their impact on ongoing projects will be discussed in the implications for future research and policy development.

Table 10 provides a summary of the number of projects covered by CAT, the associated total project value and the EU funding contribution, split by the five sub-themes. Project selection was based on projects funded by H2020, FP7 and CEF, with start dates between 2012 and 2019. This produced 238 projects.

Table 10. Connected and automated transport project summary table

Connected and automated transport theme	Total project value (million €)	Total EU contribution (million €)	Number of projects
On-board equipment	€ 149,2	€ 104,9	46
Connectivity and safety	€ 538,8	€ 339,1	83
Supporting infrastructure	€ 343,2	€ 202,9	76
Socio-economic impacts and human factors	€ 205,0	€ 172,3	49
Largescale testing	€ 571,0	€ 308,9	49

It is also possible to assess the projects by funding source, as presented in Table 11 Note that, whereas a project may research multiple sub-themes (and, therefore, double counting may appear in Table 10), each project is assigned to only one funding source in Table 11.

The sub-theme analysis has focused on projects funded by the H2020 and FP7 programmes. In addition, due to the nature of the sub-theme, projects funded by CEF are also included in the analysis. As Table 11 shows, H2020 projects covered in the analysis receive a significant EU funding contribution, followed by FP7 projects. However, the total project value is highest amongst H2020 projects, followed by CEF projects.

Table 11. CAT research by parent programme summary

Parent programme	Total project value (million €)	Total EU contribution (million €)	Number of projects
H2020	€ 779,9	€ 566,5	172
FP7	€ 205,9	€ 136,9	41
CEF	€ 306,9	€ 129,5	22

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 under each sub-theme, offering an insight into the implications for future research.

6.1 Sub-theme 1 – On-board equipment

This sub-theme focuses on projects that involve the development, validation and implementation of on-board enablers and sensors. Therefore, key technologies under this sub-theme include, but are not limited to:

- Sensor technologies for operational and environmental monitoring
- Hardware to enable ADAS (and respective non-road systems)
- On-board technologies to facilitate traffic management.

This sub-theme is important, as the technologies covered contribute to improving safety, efficiency and monitoring of connected vehicle operations. The on-board enablers contribute to vehicle operation and user experience, whilst the sensor technologies ensure safety through monitoring environmental conditions.

6.1.1 Overall direction of R&I

Several R&I areas have emerged as focal points in the development of on-board equipment for CAT. Firstly, attempts to enhance safety and security form an overarching objective for several projects. For example, projects that focus on the development of state-of-the-art sensors for vehicle, vessel, train or aircraft detection to reduce casualties and improve the safety of automated transport systems. The majority of these projects are funded by H2020 and are at the early stages of development (i.e. basic research). The majority of projects focus on the development of on-board hardware solutions, such as sensors. As mentioned, sensor-based projects are focused on the early stages of development. However, there are projects that validate and demonstrate sensor technologies. For example, ELIRAD (2016-2018), a H2020-funded project, which aimed to finalise the technical concept of a 120GHz radar sensor to address reliable operation under a wide range of environmental conditions, and ALGeSMo (2016-2019), which aimed to deliver a state-of-the-art optically-based load monitoring system for aircraft landing gear.

In addition to sensor technologies, nearly a third of the projects identified are related to the validation and deployment of systems and platforms, which support the use of on-board sensors and enablers, such as RobustSENSE (2015-2018). Several projects focus on the development of assistance systems, such as ADAS. These projects vary in objectives, with some projects aiming to enhance driver experience, whilst other projects aim to improve safety and support vulnerable transport users. These projects are also funded by H2020, yet vary in development from basic research to implementation. A few projects also focus on the development of light-weight sensor technologies for navigation, as well as software to support satellite navigation, which both aim to improve the ease and efficiency of autonomous vehicle operations.

Of all the projects allocated to this sub-theme, road transport and aviation comprise the greatest focus, representing 23 projects and 14 projects respectively. The remaining projects focus on rail, waterborne and multimodal transport.

6.1.2 R&I activities

A total of 46 projects was assigned to this sub-theme, with the vast majority funded by Horizon 2020, as highlighted in Table 12. There are no projects funded by CEF which have been assigned to this sub-theme.

Table 12. Sub-theme 1 research by parent programme summary

Parent programme	Total project value (million €)	Total EU contribution (million €)	Number of projects
H2020	€ 122,5	€ 88,7	43
FP7	€ 26,8	€ 16,2	3
CEF	-	-	0

To provide a more detailed analysis, some key projects were selected to demonstrate the core areas of research undertaken in the CAT roadmap. 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.

- AdaptIVe (2014-2017) is an FP7-funded project, which aimed to improve traffic safety by minimising the effects of human errors and enhance traffic efficiency via smoother flows and reduced congestion. AdaptIVe adopted a shared control approach, encouraging collaboration between the driver and the automated system. It aimed to develop sensors and cooperative vehicle technologies, establishing systems that dynamically respond to the situation and driver status to determine the level of automation using eight vehicle use cases.
- RobustSENSE (2015-2018) is a H2020-funded project, which involved the development of a reliable sensing and situation prediction platform, for ADAS. The project aimed to respond to the issue facing many ADASs at the time, where harsh environmental conditions posed the threat of limiting system functionality. RobustSENSE aimed to enhance the robustness of sensing methods, to improve the safe operation of automated vehicles in all conditions. Therefore, the project involved the development of a sensor platform, which focused on safety and efficiency of operation. This project has linkages with connectivity and safety sub-theme.
- SMARTER-2 (2016-2018) is a H2020-funded project, which involved surveillance of maritime transport through the use of laser technology. The project aimed to address safety, acknowledging that contact and collision incidents had become the most frequent and costly type of accident in the maritime transport sector, comprising 40 % of annual insurance claims. In particular, semi and fully submerged objects are of concern, as they remain undetected by state-of-the-art sensors (i.e. radars, sonars, optical sensors), presenting a need for improved observation capability of the ocean surface layer. Therefore, SMARTER-2 aimed to enhance the capacity to observe this challenging ocean layer, through the development of an observational sensor.
- SMART (2016-2019) is a H2020-funded project, with the primary aim to improve the quality of rail freight, through the application of automation to railway cargo across Europe. The project aimed to develop a prototype solution for obstacle detection, adopting on-board hardware and software solutions, as well as developing the interface necessary for integration into the autonomous train operation (ATO) module. SMART also aimed to develop a real-time marshalling yard management system, to decrease the time and costs associated with cargo handling.
- ALGeSMo (2016-2019) is a H2020-funded project, with the primary objective of developing a state-of-the-art optically based load monitoring system for aircraft landing gear. The project aimed to deliver a step change in the use and management of landing gear, enhancing aircraft availability and operability. It aimed to develop an optical sensor system, for detecting and translating landing gear strain and torque to the aircraft control systems. ALGeSMo also aimed to deliver an integrated photonics fibre-optic interrogator, as well as developing loading and calibration rigs, to characterise subsystem components using a full landing gear slider tube assembly.
- UP-Drive (2016-2019) is a H2020-funded project, which aims to develop an automated valet parking service for urban environments. Through this offering, the project aimed to reduce the burden on car drivers to find a parking space in city centres. UP-Drive aims to contribute towards the gradual automation of vehicles, and facilitate a safer, more inclusive transportation system. In order to achieve this, the project focused on the development of object detection technologies, mechanisms for cost-effective data management and location mapping technologies.

6.1.3 Achievements

Several projects have improved upon the current state-of-the-art in CAT. The results and achievements of these projects are presented below.

- A key objective of AdaptIVe was to highlight the importance of the human element of any partially automated solution, which played a significant role in the types of vehicle technologies tested. One of the key outcomes of AdaptIVe was the largescale testing of several combinations of sensors, including ultrasonic cameras, radars and laser scanners, furthering testing into the application of automation to perform tasks that could make driving safer. The project developed new methods for testing and evaluation, as well as highlighting pieces of legislation (such as the 1968 Vienna Convention), which require updating in line with the development of autonomous vehicle technologies. Through testing sensors and radars, and establishing a new testing framework, the project has provided the space for future projects to demonstrate and implement sensor and radar technologies. The results of the project directly feed into the L3Pilot project (discussed under the largescale testing sub-theme), which will test 100 automated vehicles in 12 European countries.

— RobustSENSE resulted in the successful development of a series of technologies. Firstly, the project defined and developed the system architecture of an environmental model, which was designed to overcome the weaknesses of existing approaches. The project also produced a prototype LIDAR sensor, as well as developing algorithms for LIDAR, radar and camera data processing to manage adverse weather conditions. RobustSENSE also developed a system performance assessment module, and integrated the module for several test vehicle demonstrations. Sensors were also enhanced according to test outcomes and their performance was validated.

— SMARTER-2 has proved a success, enabling the detection of objects, such as drifting growlers (ice floes) and floating containers, to prevent damaging collisions. The project developed and commercialised a laser detection and ranging (ladar) system, offering an innovative new sensor surveillance system which observes the ocean surface. The sensors collect information, which can be directly used by operators to reduce their operational cost. For example, through accurately observing the sea state, operators can optimise sail plan models and vessel trim, for fuel and emission savings. Due to its unique characteristics, the ladar system is suitable for a wide variety of applications, including maritime security and safety, offshore operations, fishery, environmental monitoring, dredging and offshore wind farms.

— The SMART project has delivered an obstacle detection system (ODS), offering the first system to recognise obstacles up to 200m-1000m away. SMART developed a marshalling yard management system, to enable supervision and management of marshalling yards. In addition, a novel decision-making system, adopting machine learning techniques, has also been developed. This will provide near-optimal solutions for any marshalling yard operation, simplifying business processes and contributing towards reductions in lead-time and operation costs.

— ALGeSMo has made significant progress to date, through developing landing gear load measurement systems. The project is working on the development of a Fibre Bragg Grating (FBG) optical sensor system, which aims to accurately detect and translate landing gear strain and torque to the aircraft control systems. The project is also in the process of developing an integrated photonics fibre-optic interrogator, which aims to deliver a step change in the market, through delivering the smallest system currently available on the market. As the project reaches its final stages and key results are released, it will be important to assess its impact on aircraft availability and operability.

— UP-Drive is an ongoing project, with the key objective of improving existing systems for automated driving in urban environments. To date, the project has focused on developing two vehicle platforms, integrated with environmental perception. Two operational vehicles with up-to-date systems have been developed, and integration and testing of all relevant components has been undertaken.

6.1.4 Implications for future research

The majority of on-board equipment projects covered by the analysis are at the early stages of development. Therefore, many of the projects have set the foundation for further development, with validation, demonstration and implementation still necessary. Under this sub-theme, the development of sensor technologies and on-board enablers is still necessary, as the majority of EU-funded projects (e.g. RobustSENSE and SMART) have yet to achieve largescale demonstration or implementation. Therefore, building upon these projects will enable technologies to develop beyond the initial research development phases, to reach demonstration and implementation. However, it is important to note that the private sector is investing in the demonstration of on-board technologies. For example, Tesla has released a chip to support camera-based sensors, which aims to improve data processing and decision-making in automated vehicles[51].

In addition, projects that address sensor performance and cost-effectiveness also continue to be important. Research which contributes to reducing LIDAR costs, or develop cost-effective alternatives, with comparable performance, still require investment. R&I in radar and camera-based systems, as well as the required processing software and hardware to accompany these systems, should continue. Requirements for sensors are likely to be different across different vehicle modes, due to performance, size and weight requirements, so these would require development in parallel with embedded knowledge sharing. Testing and validation of such systems also requires further research.

As many projects are developing solutions to similar issues, there is greater scope to enhance collaboration. In the application of sensor technologies, this is particularly applicable, as sensor solutions that are more reliable and can cope with a broader range of weather or environmental conditions (RobustSENSE) can be integrated

[51] https://www.theverge.com/2019/4/22/18511594/tesla-new-self-driving-chip-is-here-and-this-is-your-best-look-yet

with non-automotive applications (e.g. SMARTER 2 and SMART). Similarly, projects looking to improve the human-machine interface (AdaptIVe) could be based on latest developments in sensor capabilities, in automotive transport and other modes.

The UP-Drive project highlighted the success of industry and academia collaboration, referring to the ability of academic experts to encourage the development of innovative ideas, whilst industry partners provide academics with the opportunity to test software in real-world conditions. Although a relatively regular custom, this could be a learning for other research projects aiming to bring benefit to both academia and industry.

As the majority of projects allocated to this sub-theme cover road and air transport, there is scope for upcoming research to focus on the development and implementation of on-board enablers for rail, waterborne and multimodal transport.

6.1.5 Implications for future policy development

The projects completed under this sub-theme offer significant innovations in addressing the development of on-board enablers and sensors. In 2018 the EC released an Automated Mobility Strategy as part of the wider Europe on the Move III policy package (European Commission, 2018b), which outlines the Commission's standpoint on connected and automated mobility. The strategy highlights the EC's willingness to offer financial support to encourage private investment in technologies to support the uptake of connected and autonomous vehicles. Substantial research and investment continue to be required into the development of fundamental technologies for CAT, such as sensors, processing software and hardware.

In addition, the development of ITS technologies is supported by the ITS Directive[52] (2010/40/EU), which sets the legal framework for the deployment of ITSs in road transport, as well as providing a series of policy measures to support accessibility of EU-wide multimodal travel information for ITS users. Therefore, current policy appears to support the development of connected and automated vehicle technologies. Although it may be too soon for technology standards to be implemented, as sensor and enabler technologies develop more specific legal, insurance and testing frameworks may become appropriate. A number of MS have already implemented their own frameworks. For example, in Germany, the 2017 Autonomous Vehicle Bill outlined the requirements for fully (and highly) automated vehicles, as well as covering driver rights. France, Italy, Spain and the UK have also designed frameworks for automated vehicles.

6.2 Sub-theme 2 – Connectivity and safety

This sub-theme focuses on projects that involve vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies, as well as projects to deliver security and safety improvements in connected and automated transport networks. Therefore, key technology themes include, but are not limited to:

- Network information, management and control systems.
- Traffic management systems for improving safety.
- Communication and connectivity technologies (i.e. V2V and V2I).

[52] Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport

This sub-theme is important, as the technologies examined contribute towards improvements in the safety and security of automated vehicle operations. In addition, through the development and implementation of communication technologies, the projects also aim to enhance the efficiency and connectedness of automated vehicle operations.

6.2.1 Overall direction of R&I

Several areas of R&I have emerged as principal themes in the development of connectivity and safety technologies (the sub-theme with the greatest number of projects assigned). Firstly, communication networks and systems that adopt V2I and V2V technologies are a key focus, with these projects relating to improved road safety and the facilitation of safe platooning. These projects are funded by H2020 and FP7, and range in development phase from basic research to implementation.

A number of projects involve the development of traffic management systems to improve the ease of automated vehicle operations. These include projects to improve signalling and automation systems and to integrate and standardise traffic management systems. The majority of these projects are funded by H2020 and range from basic research to demonstration. Therefore, the major part of the projects covered by this sub-theme are focused on the development of software and systems, to enhance connectivity and improve safety. Due to the use of signalling and satellite technologies to facilitate safety improvements and communication, there are some overlaps between this sub-theme and the on-board equipment sub-theme.

Of all the projects allocated to this sub-theme, road transport and aviation are the main focus, representing 45 projects and 18 projects respectively. The remaining projects focus on rail, waterborne and multimodal transport.

6.2.2 R&I activities

A total of 83 projects were assigned to this sub-theme, with the majority funded by H2020, as highlighted in Table 13.

Table 13. Sub-theme 2 research by parent programme summary

Parent programme	Total project value (million €)	Total EU contribution (million €)	Number of projects
H2020	€ 304,9	€ 201,3	50
FP7	€ 89,9	€ 58,6	20
CEF	€ 144,0	€ 79,3	13

A number of key projects have been selected to demonstrate the core areas of research undertaken under this sub-theme. The projects selection is based on one or more of the following criteria: available project results; recent project completion date and high project value.

— ENSEMBLE (2018-2021) is a H2020-funded project, which aims to encourage the adoption of multi-brand truck platooning in Europe, to improve traffic safety and fuel economy. The key objectives of ENSEMBLE are to achieve safe platooning for trucks of different brands, define road approval requirements, including V2I communication, and work towards the standardisation of different aspects of platooning. The project will be accompanied by platooning demonstrations, to assess the real-life impacts of the project on a C-ITS corridor. The tests will examine the impact on traffic, infrastructure and logistics.

— CONCORDA (2017-2020) is a H2020-funded project that aims to assess the performance of hybrid communication systems in terms of reliability and availability. The project also aims to enhance localisation services and contribute towards the development of a new standard of evaluation of the existing standards, such as the European Telecommunications Standards Institute (ETSI) and C-ITS. CONCORDA intends to contribute to improving the interoperability and continuity of services.

— X2RAIL-2 (2017-2020) is a H2020-funded project that aims to enhance railway-signalling systems, with satellite technology, sensors and digital interfaces. The project will increase functionalities of existing signalling and automation systems, as well as enhancing design and validation processes to develop an improved intelligent traffic management system, whilst maintaining compatibility with the existing European Rail Traffic Management System (ERTMS). More specifically, the project aims to develop four selected key technologies in the field of railway signalling and automation: fail-safe train positioning; on-board train integrity; formal methods and traffic management evolution.

— EfficienSea 2 (2015-2018) is a H2020-funded project that aimed to support the development of marine traffic management systems by improving navigational safety and efficiency and enhancing emergency response. EfficienSea 2 also aimed to develop 'Maritime Cloud', a communication framework to enhance the ability of key stakeholders to share knowledge and data. The project aimed to improve ship connectivity and standardise approaches to traffic management across the sector. In addition, the project planned to showcase solutions in the Arctic and Baltic regions, through web-based implementation.

6.2.3 Achievements

— ENSEMBLE is an ongoing project, which is working to conduct the final steps necessary to achieve full deployment of multi-brand truck platooning. The project will deliver demonstrations of six branded trucks in one or more platoons, under real-world traffic conditions across national borders. Through extending the state-of-play of multi-truck platooning beyond validation and demonstration, the project aims to enhance road safety, improve traffic management through maximising the utilisation of road capacity and reduce the total cost of logistics.

— CONCORDA aims to build upon the work undertaken by previous projects, respecting the C-ITS services deployed under the C-Roads Initiative. It will contribute to the preparation of European motorways for automated driving and high-density truck platooning with adequate connected services and technologies. The main objective of the project is to assess the performance of hybrid communication systems combining 802.11p and LTE under real traffic situations. These communication systems will be tested in Belgium (E313 and E19), Germany (A9), France (C-ITS deployment test site), and Spain (Galicia ITS corridor) and the Netherlands (three pilot sites). As the project is still underway, evaluating the outcomes of the testing solutions will be of paramount importance when the project comes to a close.

— X2RAIL-2 is an ongoing project, which aims to employ formal methods for the development, verification and validation of railway signalling systems. The project aims to adopt formal methods across different phases, assessing use cases for railway signalling and undertaking formal verification. To date, the project has developed a short-list of formal and semi-formal methods. As the project continues, the key technologies developed for railway signalling and automation should be assessed, to determine the remaining research required to bring these solutions to market.

— EfficienSea 2 has successfully implemented smart solutions for efficient, safe and sustainable traffic at sea, through enhancing ship connectivity. EfficienSea 2 has been a demonstrator in the Arctic and Baltic Sea, developing the first generation of a coherent e-Navigation solution. The project has paved the way for a global rollout of its e-Navigation solution, through establishing global collaboration links, using open source software and establishing an explicit aim for standardised solutions.

6.2.4 Implications for future research

To date, the majority of projects aiming to enhance connectivity and safety have focused on the early stages of technology development (i.e. basic research). As such, many of the projects under this sub-theme provide the foundation for further development.

Although there are a couple of projects dedicated to the development of direct, cellular and hybrid communication technologies, further research is required to bring these solutions to implementation. CONCORDA offers a largescale project, with significant funding, which will provide a comprehensive review of existing communication systems, and is accompanied by demonstrations across Europe. However, there are few projects which focus on basic research into the communication technologies themselves, and therefore, additional research into this area could be valuable. Projects that show deeper integration between fully or partially automated vehicles and connectivity with infrastructure, other vehicles and other connected devices and users (V2X) should be encouraged, especially those can have a positive impact on safety.

Despite the focus of some projects on non-road technologies, such as EfficienSea 2 and X2RAIL-2, the majority of projects focus on road transport. Therefore, there is greater scope to focus research on the development of connectivity and safety technologies for aviation, rail and waterborne transport.

6.2.5 Implications for future policy development

The projects completed under this sub-theme provide extensive research into V2V, V2I and other vehicle communication technologies, as well as projects fostering wider improvements in the safety and security of automated systems. A key research area fundamental to ensuring the safety of automated systems and enabling efficiency gains and ease of operation through effective communication technologies, this area of research could benefit from funding to increase the number of projects reaching implementation stage.

It is essential that policy provide technology neutral support, supporting the implementation of direct, cellular and hybrid communication technologies, to ensure that there are no barriers to developing this essential component of connected and automated vehicle operations, from research to implementation. There is a significant amount of innovation and development taking place in this area, policy should avoid impeding these early developments.

6.3 Sub-theme 3 – Supporting infrastructure

This sub-theme focuses on projects that involve the development of both digital and physical infrastructure to support CAT. Key technologies under this sub-theme include, but are not limited to:

- AI and big data applications.
- Human-machine interface applications.
- Physical infrastructure to support connected and automated transport.

This sub-theme is important, as the technologies covered provide the necessary system architecture and physical infrastructure to support the deployment of connected and automated transport.

6.3.1 Overall direction of R&I

Several areas of R&I have emerged as focal points in the development of supporting infrastructure. Firstly, applications of big data, machine learning and artificial intelligence are prevalent in this field of research. For example, there are projects that focus on the use of AI to facilitate flight control systems, whilst others use AI to enable vehicle predictive maintenance. In addition, several projects draw upon big data to improve the management of transport operations. The majority of these projects are funded by H2020, and are at an early stage of development (i.e. basic research).

Several projects focus on the development of physical infrastructure systems and technologies to support physical infrastructure in its role within CAT. These projects vary with some aiming to enhance road infrastructure and transport models, whilst others focus on creating future-ready stations to support connected and autonomous vehicles. However, the overarching theme of these projects is the development of infrastructure that has the capacity to support the transition towards the uptake of connected and autonomous vehicles. These projects are also funded by H2020, yet vary in development from basic research to validation.

However, it is important to note that digital infrastructure projects comprise the majority of projects under this sub-theme, as the STRIA roadmap on transport infrastructure examines physical infrastructure projects in detail.

Of all the projects allocated to this sub-theme, the majority focus on road transport and aviation, representing 34 projects and 18 projects respectively. The remaining projects focus on rail, waterborne and multimodal transport.

6.3.2 R&I activities

A total of 76 projects were assigned to this sub-theme, with the majority funded by H2020, as highlighted in Table 14.

Table 14. Sub-theme 3 research by parent programme summary

Parent programme	Total project value (million €)	Total EU contribution (million €)	Number of projects
H2020	€ 228,5	€ 160,0	64
FP7	€ 34,4	€ 24,1	9
CEF	€ 80,2	€ 18,9	3

A number of key projects have been selected to demonstrate the core research areas undertaken under this sub-theme, and to provide a detailed assessment. 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.

— OPTIMUM (2015-2018) is a H2020-funded project, which aimed to provide the required interoperability and adaptability in modern transport systems. The project aimed to establish a scalable architecture for the management of big data, to enable monitoring of transport system needs. OPTIMUM adopted a cognitive approach, for continual situational awareness. The project aimed to advance state-of-the-art traffic modelling, behavioural analysis, big data processing, predictive analysis and persuasive technologies. The project also aimed to deploy the solution through real-life pilots, to test challenging use cases.

— AutoMat (2014-2018) is a H2020-funded project, which aimed to create an open ecosystem for key stakeholders to provide vehicle data. The project aimed to establish a single point of data access for all service providers, as well as providing a standardised interface for data access. It defined a prototype for a big data marketplace concept, to act as a mediator between service providers and vehicle data. AutoMat also aimed to validate the marketplace concept, through developing cross-sectoral use cases and to develop a market business model.

— TIMON (2015-2018) is a H2020-funded project, which aimed to develop real-time services for optimised multimodal mobility. The key objective of the project was to improve the safety, sustainability and efficiency of road transport systems, by processing open transport data. The project developed a cooperative open web-based platform and mobile application, with the purpose of delivering information to drivers, businesses and vulnerable road users (VRUs). TIMON aimed to empower drivers to deliver data to the platform, and therefore, increase the information available on traffic for all users.

— INFRAMIX (2017-2020) is a H2020-funded project, which also falls under the Innovation and Networks Executive Agency (INEA) automated road transport projects list[53]. The key aim of the project is to prepare road infrastructure to support the coexistence of conventional and automated vehicles. The primary target is to design, adapt and test physical and digital elements of road infrastructure, to facilitate predictable, safe and efficient traffic loads. The project will involve the use of existing simulation tools, as well as the implementation of traffic estimation and control algorithms, adapted to relevant scenarios, to identify adaptations for physical and digital road infrastructure.

— RCMS (2015-2017) is a H2020-funded project, which involved the development of innovative, robotic container management systems (RCMS). The project developed a detailed simulation model for RCMS, to

[53] https://ec.europa.eu/inea/en/horizon-2020/h2020-transport/projects-by-field/480

be later demonstrated in ports and terminals at Gdansk and Koper. RCMS assess performance relative to existing container management technologies. In addition, the project assessed the impact of RCMS with regard to efficiency, reliability and wider environmental impacts.

6.3.3 Achievements

- One of OPTIMUM's key deliverables is the release of a multimodal route-planning app, which features smart notifications and proactive recommendations to encourage more environmentally minded transport behaviour. The app, which is available via the Google Play Store, supports route planning in three cities: Birmingham, Ljubljana and Vienna. Therefore, the project has effectively addressed the aim to enable comprehensive observations of the transport ecosystem, through the development of a smart sensing system, deploying real-world pilots and supporting proactive decisions and sustainable transport behaviours through information provision.
- AutoMat aimed to create an OEM-independent vehicle data marketplace, to facilitate the development of new services. The project adopted the vision that vehicles are a 'moving collection of sensors', creating an open ecosystem for the provisioning of vehicle data, independent of manufacturers and service providers. The project also developed a specification of the Common Vehicle Information Model (CVIM) data format, to enable harmonised dataset development.
- TIMON worked to address traffic accidents, congestion and the environmental impact of transport in cities, through the development of a cooperative ecosystem. The project developed a cloud-based system, using data from transport users, open data and vehicle-to-everything (V2X) communications. The system then used artificial intelligence techniques to process the data and provide real-time planning services to users through a smartphone application. Through this app, the project offered road status and planning alert services, as well as enhancing the accuracy of vehicle and VRU positioning to improve safety. Two pilot projects were deployed in Helmond and Ljubljana, with Ljubljana attracting 238 end users to engage with the TIMON app.
- INFRAMIX is an ongoing project, which uses simulation tools, develops new methods for traffic modelling and implements traffic estimation and control algorithms to identify solutions to improve digital and physical infrastructure in relation to automated transport. The project adopts a bottom-up approach, developing three high-value traffic scenarios for testing these solutions, namely dynamic lane assignment, roadworks and bottlenecks. It also introduces a simple classification scheme, similar to SAE levels, the Infrastructure Support Levels for Automated Driving (ISAD)[54]. ISAD levels can be assigned to parts of the network in order to give automated vehicles and their operators guidance on the "readiness" of the road network for the future highway automation era. INFRAMIX focuses on motorways, yet the results are expected to be transferrable to urban scenarios. The solutions will be assessed via simulation and through demonstration along stretches of the motorway. The project aims to enhance safety, quality of service, user acceptance and efficiency.
- RCMS developed a robotic parking system, capable of efficiently managing and handling more containers per square metre than traditional systems applied in port and inland terminal settings. The system developed is adaptable to the needs of shipping companies and port terminal operators, as well as truck and railway organisations. Therefore, RCMS has developed an advanced container management system, with multimodal application.

6.3.4 Implications for future research

The focus of projects allocated to the supporting infrastructure sub-theme vary, as these projects involve digital and physical infrastructure applications for several projects. The majority of projects under this sub-theme fall under the basic research development phase. Therefore, many of the projects have provided the basis for further development, and could benefit from follow-up projects to test solutions and bring commercial propositions to market.

Several of the projects examined, including RCMS, display benefits to manufacturers and service providers, through developing digital and physical infrastructure innovations that enhance the efficiency of operations. User-centric projects are also well researched, with projects such as TIMON and OPTIMUM aiming to deliver benefits to transport users through using transport data to enhance safety, reducing congestion and improving the accessibility of multimodal travel. With big data, artificial intelligence and human-machine interface (HMI)

[54] https://www.inframix.eu/infrastructure-categorization/

applications are relatively new-to-market, further investments in their applications are necessary to shift the average development phase from basic research to demonstration and implementation. In addition, the majority of projects focus on road and air transport. There is greater scope to focus research on big data and artificial intelligence applications for aviation, rail and waterborne transport.

Although the majority of projects focus on the development of digital infrastructure, projects such as INFRAMIX, have researched the role of physical infrastructure in facilitating connected and automated transport. An area of further research could be the utilisation of data to improve physical infrastructure design with connected vehicles in mind, are those few projects that do this. However, we expect that the majority of projects relating to physical infrastructure to fall under the STRIA infrastructure roadmap. Further research in supporting physical infrastructure is covered under the TRIMIS report on transport infrastructure R&I (Gkoumas et al. 2019).

6.3.5 Implications for future policy development

The projects completed under this sub-theme provide innovative applications of big data, machine learning and artificial intelligence to connected and autonomous transport. A few of these projects take solutions to demonstration stage, and therefore, the support of European policy for the largescale deployment of connected and automated mobility, as part of the DSM strategy, is key.

As artificial intelligence and machine learning applications are still relatively new to market, it will be important for future policy development to support the development of these technologies. In addition, as the majority of projects assigned to this sub-theme relate to the use of data, and in the case of Automat, create an open ecosystem for key stakeholders to provide vehicle data, it is essential that policy is clear on data ownership and the use of data for connected and automated transport applications.

6.4 Sub-theme 4 – Socio-economic impacts and human factors

This sub-theme focuses on projects that deliver economic and social benefits to transport users and individuals working in the transport sector, as well as projects that foster broader environmental benefits. Therefore, key technologies include, but are not limited to:

- Technologies to improve user acceptance.
- Systems to enhance employee wellbeing.
- Software to improve access for vulnerable transport users.

Distinct from the previous sub-themes, this sub-theme focuses on technologies that gain direct approval from transport users, or benefit transport sector employees, by improving the safety and efficiency of operations. This sub-theme also covers projects that aim to engender environmental benefits to society, or improve the economic efficiency and cost effectiveness of connected vehicle technologies. Therefore, this broad theme covers projects with the key objective of generating socio-economic and environmental benefits.

6.4.1 Overall direction of R&I

A number of topics have emerged as key areas for research, in the development of technologies aiming to deliver socio-economic and environmental impacts. Firstly, projects focusing on improving the welfare of transport sector employees, through the development of HMI systems, navigation and traffic management systems and simulators. For example, a number of projects study centring operations around the crew of aircraft and vessels, to enhance wellbeing and minimise stress. The majority of these projects are funded by H2020 and FP7, and are at the early stages of development (i.e. basic research). In addition, a few projects, such as a H2020-funded project, Levitate (2018-2021), are focusing on evaluating the broader societal impacts of connected and autonomous vehicles, through engaging with industry stakeholders or developing frameworks to assess the short-term and long-term impacts of autonomous transport through analysis of indicator sets. Therefore, under this sub-theme the projects are both software and hardware-based, as well as being involved in consensus-building and framework development.

Several projects examine the development of technologies which aim to enhance user acceptance of connected and autonomous vehicles. These projects vary in nature and scale, with one project adopting an awareness-driven approach to encourage users to see beyond the perceived barriers hindering connected and autonomous vehicle uptake. Another project aims to improve the functionality of autonomous vehicles in a series of traffic scenarios and weather conditions, with the end goal of enhancing public acceptance of autonomous vehicles. These projects are also funded by H2020, and are in the early stages of development (i.e. basic research).

In addition, there are several projects that aim to enhance safety for vulnerable transport users. For example, SUaaVE (2019-2022) involves the development of a connected and autonomous vehicle simulation, focused on human factors, to assess user acceptance and the experience of VRUs in relation of connected vehicles, with the aim of speeding up market deployment. Similarly, PROSPECT (2015-2018) developed and demonstrated on-board sensors and human-machine interfaces, to enhance VRU safety. Due to the focus on societal impacts, there are some overlaps between this sub-theme and the one on connectivity and safety.

Of all the projects allocated to this sub-theme, the main focus is on road transport and aviation, representing 26 projects and 10 projects respectively. The remaining projects focus on rail, waterborne and multimodal transport.

6.4.2 R&I activities

A total of 48 projects were assigned to this sub-theme, with the majority funded by H2020, as highlighted in Table 15. There are no projects funded by CEF that have been assigned to this sub-theme.

Table 15. Sub-theme 4 research by parent programme summary

Parent programme	Total project value (million €)	Total EU contribution (million €)	Number of projects
H2020	€ 140,4	€ 126,4	38
FP7	€ 61,6	€ 43,0	10

To provide a more detailed assessment, a number of key projects have been selected to demonstrate the core areas of research undertaken under this sub-theme. The selection was based on one or more of the following criteria: available project results; recent project completion date and high project value.

- ACROSS (2013-2016) is a FP7-funded project, which aimed to develop innovative flight deck solutions to reduce the stress experienced by pilots, through reducing their peak workload. Therefore, the project aimed to enhance flight performance and safety, through focusing on improving the wellbeing of pilots. In addition, ACROSS aimed to develop and test cockpit-based technologies to reduce the number of crew members required to safely operate flights. This will ensure that crew members are granted sufficient breaks to optimise their performance and prevent fatigue. Through building upon prior studies on workload and stress reduction for crew operations, the project aimed to identify key considerations for the implementation of single-pilot operations.
- IT2RAIL (2015-2017) is a H2020-funded project, which aimed to develop information technologies to facilitate the shift towards multimodality, through developing a technical enabler which places transport users at the centre of multimodal travel solutions. The project aims to develop a user-centric travel companion app, which addresses the key challenges of the Shift2Rail IP4 work programme. The project

aims to develop system architecture, which can be scaled for largescale implementation. Through providing a one-stop-shop for planning, ticketing and tracking, the project aims to enhance public acceptance of multimodality.

- PROSPECT (2015-2018) is a H2020-funded project, with the primary aim of enhancing pedestrian and cyclist safety. PROSPECT aimed to deliver an improved in-vehicle safety system for detecting VRUs, which uses HMI, sensors and situational analysis to detect VRUs in a variety of scenarios. In order to achieve this, the project planned to expand the scope of VRU scenarios examined and develop a solution which improved system performance more broadly, through robust detection of VRUs, collision avoidance strategies and situation analysis. PROSPECT will also aim to develop advanced HMI and vehicle control technologies, providing linkages to the first three sub-themes.
- SafeShore (2016-2018) is a H2020-funded project, which aimed to enhance coastal border security, and as such prevent cross-border crime, such as human trafficking. The SafeShore project aimed to develop a solution for detecting small objects operating at a low altitude, such as remotely piloted aircraft systems (RPAS), which can be used in human trafficking operations and drug smuggling. The project aimed to provide coastal protection through the use of three mobile platforms, capable of virtual detection using sensor and radar technology. The project also aimed to develop three prototypes for demonstration, displaying overlaps with the first sub-theme on on-board equipment and the final sub-theme on largescale testing.
- Avenue (2018-2022) is an ongoing H2020-funded project, which also falls under the Innovation and Networks Executive Agency (INEA) automated road transport projects list[55]. The project aims to enhance user acceptance of autonomous urban public transport services, through the development of integrated autonomous public transport services and the validation of autonomous vehicle safety in urban scenarios. The project also aims to evaluate the socio-economic impacts of deploying autonomous vehicles to support public transport systems in urban areas.

6.4.3 Achievements

- ACROSS delivered a series of innovative tools and guidelines, which displayed promise for contributing towards a reduction in the stress levels experienced by airline pilots and crews. The tools display the capability to increase the safety of airline transport, through reducing the likelihood of future accidents. In addition to safety and welfare improvements, the project aims to reduce the crew members required for flights in the long run and therefore, enhance the cost-effectiveness of flight operations.
- IT2RAIL developed a technical demonstrator, capable of providing the feasibility of enhancing the attractiveness of rail as a transport mode. The project delivered a user-centric application with a specialised transport account, offering access to multimodal transport offers, the ability to track journeys and insights into journey-related data. IT2RAIL delivered a number of key innovations, from the aforementioned one-stop-shop for multimodal travel, to facilitating the development of interfaces and common protocols.
- PROSPECT successfully examined relevant VRU scenarios, determining user needs, as well as developing advanced VRU sensing technologies. The project generated more accurate tracking, through radar-based and video-based obstacle detection. PROSPECT also developed advanced system control strategies, to make automatic intervention more transparent and understandable for the driver. The system makes clear the transition between warning the driver and adopting automated vehicle action, through the use of combined steering and high dynamic actuators. The project has also developed a demonstrator vehicle, which a high-resolution stereo camera system, combined with a short-range radar sensor and automatic steering and braking.
- SafeShore has contributed towards the development of a novel system for efficient detection capabilities. The project developed a system based on a 3D LIDAR system, acoustic sensors, radio detection and video analytics. Over the course of the project, SafeShore developed the initial concept for novel detection, as well as demonstrating and integrating the detection system through the production of three functional prototypes. Each of the prototypes contains multiple sensors, with the capacity to establish a virtual dome shield around the protected area, which sends out an alert if a potential threat enters the allocated zone.
- The Avenue project offers further development in the enhancement of public acceptance of automated vehicles. The project is still ongoing, yet promises a step change in the integration of autonomous vehicles into public transport networks, whilst keeping in mind the expectations of a range of user groups. The project aims to deliver four key demonstrations of the project findings in Lyon, Luxembourg, Geneva and

[55] https://ec.europa.eu/inea/en/horizon-2020/h2020-transport/projects-by-field/480

Copenhagen. These largescale demonstrations will test several use cases for autonomous vehicles for public transport. For example, the Lyon demonstration aims to accompany an on-demand shuttle service with a mobile application to drive engagement from public transport users.

6.4.4 Implications for future research

To date, the majority of projects aiming to assess socio-economic benefits have focused on the early stages of technology development (i.e. basic research). Therefore, many of the projects have set the foundation for further development, with validation, demonstration and implementation at a larger scale still necessary. Under this sub-theme, the development of technologies for VRUs and wider attempts to enhance the safety and welfare of passengers and crew, are all still relevant areas for research. Therefore, building upon projects that have since finished, such as PROSPECT and ACROSS, will enable projects to develop beyond the initial research development phases, to reach demonstration and implementation.

For several road transport projects, the research is based on the development of Apps. Therefore, future research could aim to ensure that the latest state-of-the-art data sources and data processing techniques are used, as well as facilitating largescale trials and pilots. For other modes, research is more focused on developing a combination of hardware solutions and systems. This leaves testing and validation, as well as larger scale deployment, as sensible next steps.

PROSPECT has contributed to the development of technologies aiming to enhance the safety and comfort of vulnerable road users, through the development of specialised knowledge and through piloting demonstrator vehicles to test essential use cases. For projects aiming to benefit vulnerable road users, projects which aim to facilitate implementation through commercialising technologies and establishing consensus on best practice will enable real-world impacts on road safety to be witnessed.

In regard to IT2RAIL, the project offered an initial step in the Shift2Rail journey. The project provided proof of concept and facilitated model development, yet was limited in geographical coverage and functionality. In the final outcomes, the project leads highlighted the power of combining IT2RAIL technologies with comparable European-funded projects, to optimise the capabilities of the technologies developed across the field of research.

SafeShore offers a relatively unique project, aiming to respond to the growing operation of small-scale RPASs, and the associated concern of their potential misuse. Relatively few projects in the CAT roadmap focus on border security in relation to potential human trafficking and drug smuggling. Therefore, there could be scope to develop research in this area further through scaling up and integration with similar systems. This will ensure interoperability, and encourage project outputs to keep up with state-of-the-art developments in sensor technologies.

Several projects aim to enhance public and user acceptance of autonomous vehicles, such as Avenue. Therefore, there is great potential for these projects delivery partners to engage in knowledge sharing to maximise the resource invested in these projects and shift the projects from validation and demonstration to implementation.

6.4.5 Implications for future policy development

The projects completed under this sub-theme offer significant innovations in addressing the socio-economic impacts and human factors associated with connected and autonomous vehicles. As outlined in the policy context section, European policy on connected and automated vehicles is still being developed. However, the EC released an Automated Mobility Strategy (European Commission, 2018b), as part of the wider Europe on the Move III policy package, which outlines the EC's standpoint on connected and automated mobility. The strategy highlights the EC's willingness to offer financial support to encourage private investment in technologies to support the uptake of connected and autonomous vehicles. In addition, the development in ITS technologies is supported by the ITS Directive[56] (2010/40/EU), which sets the legal framework for the deployment of ITS in road transport, as well as providing a series of policy measures to support accessibility of EU-wide multimodal travel information for ITS users.

Greater attention could be placed on the safety aspects of connected and automated vehicle research, which comprise the multitude of projects under this sub-theme. For example, projects that have produced mobile Apps

[56] Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport

to enhance road safety. Policies could enhance interoperability between the Apps, enabling data access and sharing, to maximise the positive impact on road safety for vulnerable road users and pedestrians more broadly.

In addition, technologies that have been proven successful through validation and demonstration could be encouraged through policy measures, to enhance investment from industry and encourage broader implementation.

6.5 Sub-theme 5 – Largescale testing

This sub-theme focuses on projects which deliver largescale testing and demonstrations, across all modes and technologies. Therefore, key technology themes under this sub-theme include, but are not limited to:

— Autonomous transport and logistics systems.

— Validation of freight vehicles.

— Automated driving demonstrations.

This sub-theme is important, as the projects examined aim to test software, systems, vehicles and infrastructure, to determine the feasibility of bringing solutions to market. Demonstration projects are useful, as they help parties to achieve the co-funding necessary to implement projects, which accelerates the deployment of technologies.

6.5.1 Overall direction of R&I

A number of topics have emerged as key focal points in the delivery of demonstration and largescale testing projects. Firstly, the majority of projects covered under this sub-theme involve demonstrations on the city or country-level. Eleven of the 52 projects form the country-level segments of C-Roads, a CEF-funded programme focusing on the deployment of harmonised and interoperable C-ITS services in Europe.

The technologies tested under this sub-theme vary significantly, from testing vehicle-sharing platforms and operational systems, to demonstrating autonomous bus concepts. Therefore, this sub-theme contains significant overlaps with the first three sub-themes, as projects under this sub-theme include largescale testing of on-board equipment, communication systems and digital infrastructure. The majority of the projects under this sub-theme are funded by CEF and H2020, and are at various stages of development, from basic research to implementation.

Of all the projects allocated to this sub-theme, road transport and aviation comprise the greatest focus, representing 35 projects and 7 projects respectively. The remaining projects focus on waterborne and multimodal transport.

6.5.2 R&I activities

A total of 49 projects are assigned to this sub-theme, primarily funded by H2020 and CEF, as highlighted in Table 16.

Table 16. Sub-theme 5 research by parent programme summary

Parent programme	Total project value (million €)	Total EU contribution (million €)	Number of projects
H2020	€ 205,3	€ 137,6	21
FP7	€ 88,3	€ 56,5	9
CEF	€ 277,4	€ 114,8	19

To provide a more detailed assessment, a number of key projects have been selected to demonstrate the core areas of research undertaken under this sub-theme. 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.

- ENABLE-S3 (2016-2019) is a H2020-funded project, which aimed to enable validation of automated safety and security systems. The project aimed to develop an efficient testing framework, to demonstrate the functionality and safety of automated cyber-physical systems (ACPS). The project also aimed to provide a validation environment, which would enable a simple re-qualification process, through reusing validation scenarios. EANBLE-S3 also aimed to establish open standards to support the adoption of emerging validation tools and methods for ACPS.
- CITYMOBIL2 (2012-2016) is a FP7-funded project, which builds upon the findings of a prior project, CITYMOBIL. CITYMOBIL examined four key mobility issues facing cities: congestion; land use; safety and environment. This seminal project demonstrated the potential for automated road transport to respond to these issues. However, CITYMOBIL also highlighted barriers to the deployment of automated road transport: the legal framework, implementation framework and broader economic impact of deployment. Therefore, CITYMOBIL2 aimed to address these barriers to deployment, overcome uncertainties and ease the implementation process.
- SCOOP@F Part 2 (2016-2019) is a CEF-funded project, which aimed to deliver a largescale C-ITS pilot, connecting 3,000 vehicles with 2,000 km worth of road. The project aimed to enhance the road safety of users, as well as improving traffic management. The project aimed to test the deployment of C-ITS, through developing an efficient security system to ensure the privacy of users and through preparing key industry and government stakeholders for initial deployment. The project also aimed to develop a hybrid communication system and to contribute towards the interoperability of C-ITS across the EU.
- CONSORTIS (2014-2017) is a FP7-funded project, which aimed to develop a demonstrator for real-time concealed object detection. The project involved the integration of a passive video camera and an active imaging radar system, to enable concealed object detection. CONSORTIS aimed to develop a near-real time imaging, to enable application to walk by security screening. The project aimed to develop anomaly detection algorithms, to improve automation and alleviate privacy concerns. CONSORTIS planned to undertake end user demonstration at a European airport, involving a host of ethics experts to reduce the risk of privacy issues.
- L3Pilot (2017-2021) is a H2020-funded project, which also falls under the Innovation and Networks Executive Agency (INEA) automated road transport projects list[57]. The project builds upon the AdaptiVe project, captured under the on-board equipment sub-theme, to pilot automated driving in Europe. The project aims to test the viability of automated driving, as a safe and effective mode of transport. The project aims to create a standardised approach to piloting automated driving across Europe, coordinate research and demonstration in the piloting community, evaluate automated driving functions and promote awareness of automated driving.

6.5.3 Achievements

- ENABLE-S3 developed a scenario-based verification and validation methodology and tools to address the challenges facing highly automated systems. The project evaluated tools and interfaces, which were applied in several demonstrators, to determine the next steps required to ensure that automated systems are

[57] https://ec.europa.eu/inea/en/horizon-2020/h2020-transport/projects-by-field/480

applicable for users. The project outlined the need for breaking down a single comprehensive system into multiple subsystems, to enhance the performance and reusability of simulators themselves. The project covered multiple research areas, from initially undertaking big data analysis, to simulation-based testing to developing a simulation platform for system validation. ENABLE-S3 was applied across all transport modes, as well as in farming and health applications.

- As previously stated, CITYMOBIL2 aimed to address the absence of legal and implementation frameworks, in order to support the uptake of automated transport systems. The project developed a prototype automated transport system, for testing in urban environments. The project also involved 12 partner cities undertaking a feasibility study to determine the potential for implementing automated transport systems in their respective regions. In 2014, the first of three largescale demonstrations was implemented in La Rochelle, followed by Greece and Switzerland in 2015. In each of these city-level demonstrations, six vehicles were operation for a period of at least six months. These demonstrations were accompanied by research on the financial, cultural and technical feasibility of automated vehicle deployment, exploring the impact on current infrastructure.
- Although SCOOP@F Part 2 is ongoing, the project is coming to a close. To date, the project has successfully built upon SCOOP@F Part 1, to finalise the validations of the system developed under this project. The project has also undertaken a series of pilot tests with European Member States, to determine the real-world capabilities of the system. The project aims to introduce additional services, including multimodal capabilities, as well as to develop a hybrid communication system. When the project reaches its final conclusions, it will be important to examine its complete impact on road safety and traffic management systems.
- CONSORTIS successfully developed a prototype of a real-time security screening system for application at airports. The system is capable of improved security screening, and has been developed to ensure it is less restrictive than existing systems. The primary impact of the project is the development of an innovative hardware solution, which collects security data at submillimetre-wave (SMMW) frequencies. The solution has the capacity to inform future system procurements and determine whether SMMW technology is advantageous for aviation security and other security use cases.
- L3Pilot offers some key inroads into the integration of automated vehicles into Europe's existing transport infrastructure. Researchers applied the results of AdaptiVe to L3Pilot, to assist with determining the viability of automated driving as a safe means of transport. Although still ongoing, the project has started to investigate a range of driving scenarios, from partaking to driving through urban intersections. Through this investigation, the project aims to evaluate user acceptance, driver behaviour and the potential impacts of automated driving on safety and traffic. As the project continues, it also aims to compile a list of best practices to form a Code of Practice.

6.5.4 Implications for future research

The focus of projects allocated to the largescale testing sub-theme are diverse in nature, due to their categorisation by development phase rather than thematic area. Therefore, the majority of these projects have facilitated sufficient progress in technological development, with the implementation of tested technologies being the only remaining step to bring products to market.

Despite the focus of some projects on non-road technologies, such as CONSORTIS, the majority of demonstration projects are focused on city and country-level applications, and relate to road transport. Therefore, there is scope to focus research on demonstrators for aviation, rail and waterborne transport.

CITYMOBIL2, L3Pilot and SCOOP@F Part 2 have all contributed to the demonstration of technologies and vehicles, to highlight the capabilities of connected and automated vehicles to provide efficient and safe systems, as well as display the gaps remaining to encourage further development and uptake of these vehicles.

ENABLE-S3 offered successful validation of automated safety and security systems, whilst developing an efficient testing framework. As such, safety and security is an underlying theme of the majority of these demonstration projects. Therefore, it would be beneficial to build upon the research undertaken by previous European-funded projects, as well as working alongside the private sector, to ensure that research is optimised and to deter the development of repetitive projects, which do not establish a step change in the field.

The value of large demonstration projects is to help scale up some of the early stage R&I and make adaptions necessary for real-world implementation, as well as validating the performance. As such, successful early-stage development projects that have resulted in the development of technologies or solutions that are beyond the current state of the art should be encouraged to progress to this large demonstrator/pilot phase. Cross-member state coordination and cooperation should be encouraged where possible and appropriate.

6.5.5 Implications for future policy development

The projects completed under this sub-theme provide insightful demonstrations of a range of connected and automated vehicle technologies. As outlined in the policy context, European policy has focused on facilitating a common market for the largescale deployment of Connected and Automated Mobility, as part of the DSM strategy. The EU supports three 5G cross-border corridor projects for largescale testing, co-funded under H2020. Regarding other modes of transport, the EC has promoted two large industrial projects, SESAR and ERTMS, related to connectivity in air and rail transport, respectively. Therefore, sufficient policy is in place to support the development of demonstration and largescale testing projects.

As stated, greater attention could be placed on the safety aspects of connected and automated vehicle research. In addition, if border security projects, such as CONSORTIS, become prevalent, policy relating to unmanned aerial vehicles may require updating to align with safety and security concerns.

Given the early stage of market development for many of the technologies, innovation should not be restricted with unnecessary standardisation. However, policy around cooperation and collaboration between Member States could help to ensure demonstration, and early stage implementation, of technologies and solutions that are more likely to be developed in a way that makes them interoperable in the longer term.

7 Conclusions

Focusing on selected EU funded projects from 2012 onwards, this report presents a comprehensive analysis of European R&I in CAT. It identifies relevant researched technologies and their development phase and highlights the relevant policy context and the market activities both in Europe and outside. Based on the assessment, the following key conclusions can be drawn:

— Under FP7 and H2020 over €1.5 billion has been invested in CAT research projects. This includes €1 billion of EU funds and about €500 million of own contributions by beneficiary organisations.

— Between 2007 and 2013, the FP7 programme funded 129 projects relevant to CAT technologies, with a total budget of €704 million. Most of the projects were funded through the transport and ICT programmes of FP7. From 2014, projects were funded through H2020; 173 relevant projects have been identified in the TRIMIS database, with €786 million of total funding. 73% of this budget has been funded through the Smart, Green and Integrated programmes within the Societal Challenges section of H2020.

— A total of 1,526 unique organisations participated in FP7 and/or H2020 projects on CAT. Some organisations focus exclusively on CAT research in one mode of transport, whereas others conduct research across modes. Of the top 15 beneficiaries, 15 are active in road, four in rail, five in multimodal, six in air, and two in waterborne transport.

— Spending on CAT research under H2020 peaked at the beginning of 2018. Road transport received greatest interest, while waterborne transport receives the smallest amount of funds for CAT research amongst all modes.

— From a text analysis on scientific research from the Scopus database, the number of publications in CAT in general has an increasing trend from year to year. *Connectivity and safety* and *on-board equipment* are the most present subthemes. EU has the highest number of scientific publications, followed by the US and China, respectively. Even though China has the most publications in *Connectivity and safety*, their scientific production on *on-board equipment* and *largescale testing* is limited. When compared to US publications, EU has a larger number of publications on all topics, except for *largescale testing*. On a broader scale, the evolution of CAT related publications throughout 2005 to 2019 suggests that there has been a slow growth of publications until 2015, when there is a great increase. Scientific production on *Socio-economic impacts* and *human factors* is increased in 2018 and 2019.

— The technology analysis highlights clusters that are researched in FP programmes at different development phases. The concept of development phase as an indication of technology maturity has been consolidated in the TRIMIS assessment methodology and is widely used in this report.

Findings on the R&I related to the five sub-themes are presented below.

On-board equipment sub-theme:

— The majority of projects covered by the analysis are at the early stages of development, at basic research. Therefore, many of the projects have set the foundation for further development. The development of sensor technologies and on-board enablers is still necessary, as the majority of EU-funded projects under this sub-theme, have yet to achieve largescale demonstration or implementation. Building upon these projects to validate technologies will enable technologies to develop beyond the initial research development phases, to reach demonstration and implementation. However, it is important to note that the private sector is investing in the demonstration of on-board technologies.

— Projects that address sensor performance and cost-effectiveness also continue to be important. Research projects that aim to reduce LIDAR costs, or develop cost-effective alternatives, with comparable performance, still require investment. In addition, R&I in radar and camera-based systems, as well as the required processing software and hardware to accompany these systems, should continue. Requirements for sensors vary across different vehicle modes, due to performance, size and weight requirements, and therefore require development in parallel with embedded knowledge sharing. Testing and validation of such systems also requires further research.

— As many projects are developing solutions to similar issues, there is scope to enhance collaboration. In the application of sensor technologies, this is particularly applicable, as sensor solutions that are more reliable and can cope with a broader range of weather or environmental conditions can be integrated with non-automotive applications. Similarly, projects looking to improve the HMI could be based on latest developments in sensor capabilities, in automotive transport and other modes.

- As the majority of projects allocated to this sub-theme cover road and air transport, there is scope for upcoming research to focus on the development and implementation of on-board enablers for rail, waterborne and multimodal transport.

Connectivity and safety sub-theme:

- The majority of projects aiming to enhance connectivity and safety have focused on the early stages of technology development (i.e. basic research). As such, many of the projects under this sub-theme have set the foundation for further development. This is true for direct, cellular and hybrid communication technologies.
- There are few projects that focus on basic research into the communication technologies. Further research into this area could be valuable. Projects that show deeper integration between fully or partially automated vehicles and connectivity with infrastructure, other vehicles and other connected devices and users (V2X) should be encouraged; especially those can have a positive impact on safety.

Supporting infrastructure sub-theme:

- Projects on the supporting infrastructure sub-theme involve digital and physical infrastructure applications. The majority of projects under this sub-theme fall under the basic research development phase. Therefore, many of the projects have provided the basis for further development, and could benefit from follow up projects to test solutions and bring commercial propositions to market.
- Several of the projects examined, display benefits to manufacturers and service providers, through developing digital and physical infrastructure innovations that enhance the efficiency of operations. There are many user-centric projects which aim to deliver benefits to transport users through using transport data to enhance safety, reducing congestion and improving the accessibility of multimodal travel. With big data, artificial intelligence and human-machine interface applications still relatively new-to-market, further investments in their applications are still necessary to shift the average development phase from basic research to demonstration and implementation. In addition, the majority of projects focus on road and air transport. There is scope to focus research on big data and artificial intelligence applications for aviation, rail and waterborne transport.
- Although the majority of projects focus on the development of digital infrastructure, some projects, have researched the role of physical infrastructure in facilitating connected and automated transport. Since there are relatively few projects under this sub-theme that utilise data to improve physical infrastructure design with connected vehicles in mind, this could be an area for further research.

Socio-economic impacts and human factors sub-theme:

- The majority of projects that assess socio-economic benefits so far focus on the early stages of technology development (i.e. basic research). Therefore, many of the projects have set the foundation for further development, with validation, demonstration and implementation at a larger scale still necessary. Under this sub-theme, the development of technologies for vulnerable road users and wider attempts to enhance the safety and welfare of passengers and crew, are all still relevant research areas. Therefore, building upon projects that have since finished, will enable projects to develop beyond the initial research development phases, to reach demonstration and implementation.
- For several road transport projects, the research is based on the development of Apps. Future research should ensure that the latest state-of-the-art data sources and data processing techniques are used, as well as facilitating largescale trials and pilots. For other modes, research is more focused on developing a combination of hardware solutions and systems. This leaves testing and validation, as well as larger scale deployment, as sensible next steps.
- Several projects aim to enhance public and user acceptance of autonomous vehicles. Therefore, there is great potential for these projects delivery partners to engage in knowledge sharing to maximise the resource invested in these projects and shift the projects from validation and demonstration to implementation.

Largescale testing sub-theme:

- The focus of projects allocated to the largescale testing sub-theme are diverse in nature, due to their categorisation by development phase rather than thematic area. Therefore, the majority of these projects have facilitated sufficient progress in technological development, with the implementation of tested technologies being the only remaining step to bring products to market.

- Despite the focus of some projects on non-road technologies, the majority of demonstration projects are focused on city and country-level applications, and relate to road transport. Therefore, there is greater scope to focus research on demonstrators for other transport modes, waterborne transport in particular.
- Safety and security are an underlying theme of the majority of demonstration projects. Therefore, it would be beneficial to build upon the research undertaken by previous European-funded projects, as well as working alongside the private sector, to ensure that research is being optimised and to dissuade the development of repetitive projects, which do not establish a step change in the field.

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

- The TRIMIS projects and programmes database has only recently been consolidated, yet there are some issues that could be addressed better in the future.
- The technology identification and the corresponding development phase assessment (Section 5), is on-going, and the technology taxonomy has not reached yet a full maturity. Likewise, the methodology behind the text analysis on CAT academic research is expected to be more thorough in future reports

Altogether, this report provides a comprehensive and up-to-date review of CAT R&I across Europe. Although with limitations (more notably, the lack of MS projects in the assessment), findings and insights into the current R&I status and future needs, help the STRIA WG to better identify R&I activities and provides valuable information to connected and automated transport stakeholders.

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List of abbreviations and definitions

A*STAR	Agency for Science, Technology and Research
ACEA	European Automobile Manufacturers' Association
ALT	Alternative Energy
AT	Austria
ATO	Autonomous Train Operation
ATP	Automatic Train Protection System
BE	Belgium
BG	Bulgaria
CAT	Connected & Automated Transport
CAM	Connected and automated mobility
CCAM	Cooperative connected and automated mobility
CCNR	Central Commission for the Navigation of the Rhine
CEDR	Conference of European Directors of Roads
CEF	Connecting Europe Facility
C-ITS	Cooperative Intelligent Transport Systems
CO_2	Carbon dioxide
CORDIS	Community Research and Development Information Service
COST	Co-Operations in Science and Technology
CY	Cyprus
CZ	Czech Republic
DE	Germany
DG MOVE	Directorate-General for Mobility and Transport
DG RTD	Directorate-General for Research and Innovation
DK	Denmark
DOT	Department of Transportation
DSM	Digital Single Market
DSRC	Dedicated short-range communication
EC	European Commission
EE	Estonia
EL	Greece
ELT	Electrification
ERRAC	European Rail Research Advisory Council
ERTMS	European Rail Traffic Management System
ERTRAC	European Road Transport Research Advisory Council
ES	Spain
ETCS	European Train Control System
EU	European Union

EU-13	Group of 13 EU countries: Bulgaria (BG), Czech Republic (CZ), Croatia (HR), Cyprus (CY), Estonia (EE), Hungary (HU), Latvia (LV), Lithuania (LT), Malta (MT), Poland (PL), Romania (RO), Slovakia (SK) and Slovenia (SI)
FBG	Fibre Bragg Grating
FHWA	Federal Highway Administration
FI	Finland
FMCSA	Federal Motor Carrier Safety Administration
FP	Framework Programme
FP7	Seventh Framework Programme
FR	France
FTA	Federal Transit Administration
GNSS	Global Navigation Satellite Systems
GSM	Global System for Mobile Communications
GSM-R	Global System for Mobile Communications – Railway
H2020	Horizon 2020 Framework Programme
HR	Croatia
HU	Hungary
IE	Ireland
IEC	International Electrotechnical Commission
INF	Infrastructure
IoT	Internet of Thing
ISAD	Infrastructure Support Levels for Automated Driving
IT	Italy
ITS	Intelligent Transport Systems
JPO	Joint Program Office
JRC	Joint Research Centre
Ladar	Laser detection and ranging
LIDAR	Light detection and ranging
LT	Lithuania
LTA	Land Transport Authority
LU	Luxembourg
LV	Latvia
MaaS	Mobility-as-a-Service
MASS	Maritime Autonomous Surface Ships
MS	Member States
MT	Malta
NASA	National Aeronautics and Space Administration
NETT	New and emerging technologies and trends
NHTSA	National Highway Traffic Safety Administration
NL	Netherlands

NRAs	National Road Authorities
NTM	Network & Traffic Management
ODS	Obstacle Detection System
PL	Poland
PRT	Personal Rapid Transport
PT	Portugal
REGEX	Regular expressions
R&I	Research and innovation
RO	Romania
SAE	Society of Automotive Engineers
SAVI	Singapore Autonomous Vehicle Initiative
SE	Sweden
SESAR	Single European Sky ATM Research
SI	Slovenia
SIP	Japan's Cross-Ministerial Strategic Innovation Promotion Program
SK	Slovakia
SME	Small Medium Enterprise
SMMT	Society of Motor Manufacturers and Traders
SMMW	Submillimetre-wave
SMO	Smart Mobility
STRIA	Strategic Transport Research and Innovation Agenda
TEN	Trans-European network
TEN-T	Trans-European transport network
TRIMIS	Transport Research and Innovation Monitoring and Information System
TRL	Technology readiness level
UK	United Kingdom
US	United States
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
V2X	Vehicle-to-everything
VDM	Vehicle Design & Manufacturing
VRU	Vulnerable Road Users
WG	Working Group

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Annexes

Annex 1: Project table

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

Project acronym	Project name	Project duration	Source of funding	On-board Equipment	Connectivity and Safety	Supporting Infrastructure	Socio-economic Impacts	Largescale Testing
2MOVE2	New forms of sustainable urban transport and mobility	2012-2016	FP7-TRANSPORT					Y
A3R	Air To Air Automatic Refuelling	2016-2016	H2020-EU.3.4.			Y		
ACROSS	Advanced Cockpit for Reduction Of StreSS and workload	2013-2016	FP7-TRANSPORT		Y		Y	
AdaptIVe	Automated Driving Applications and Technologies for Intelligent Vehicles	2014-2017	FP7-ICT	Y				Y
ADASANDME	Adaptive ADAS to support incapacitated drivers Mitigate Effectively risks through tailor made HMI under automation	2016-2020	H2020-EU.3.4.	Y	Y			Y
ADS Project	Autonomous Dronistics for Security (ADS): optimized services with fleets of flying robots	2015-2015	H2020-EU.2.1.	Y				
AEROGLASS	Augmented reality aerial navigation for a safer and more effective aviation	2015-2017	H2020-EU.3.4.	Y		Y		
Aerowash II	InnovAtive automatic battERy pOwered WASHing robot for the aviation industry - Aerowash II	2015-2015	H2020-EU.3.4.			Y		

AINARA	Automation and INtelligence solutions for Automated Road trAnsport systems	2015-2017	H2020-EU.3.4.			Y		
AIRBEAM	AIRBorne information for Emergency situation Awareness and Monitoring	2012-2015	FP7-SECURITY		Y			Y
AIRPASS	Advanced Integrated RPAS Avionics Safety Suite	2017-2019	H2020-EU.3.4.	Y				
ALBORA	Next-generation navigation technologies for autonomous vehicles	2018-2018	H2020-EU.2.1.	Y				
ALGeSMo	Advanced Landing Gear Sensing and Monitoring	2016-2019	H2020-EU.3.4.	Y		Y		
AMBRA	AMBRA-Electrify Europe	2018-2022	CEF			Y		Y
AMOR	A Mile Of Runway	2015-2017	H2020-EU.3.4.		Y			
AMPWISE	Autonomous Wireless Current Sensor for Aircraft Power Lines	2018-2021	H2020-EU.3.4.	Y				
ANGELS	Advanced Next GEneration Landing System	2015-2017	H2020-EU.3.4.		Y	Y	Y	
ANGI-HUD	Next Generation Cockpit HUD Integration	2016-2019	H2020-EU.3.4.			Y		
A-PIMOD	Applying Pilot Models for Safer Aircraft	2013-2016	FP7-TRANSPORT		Y	Y		
ARCADE	Aligning Research & Innovation for Connected and Automated Driving in Europe	2018-2021	H2020-EU.3.4.				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	2016-2019	H2020-EU.3.4.		Y			
ARIESS	Augmented Reality and Indoor Navigation for Enhanced ASSembly	2017-2020	H2020-EU.3.4.			Y		
ASCENT	Active Simulator Cockpit Enhancement	2017-2019	H2020-EU.3.4.					Y
AST-FCS_vF	Adaptive Self-Tuning Flight Control System Complete and Qualified	2014-2015	H2020-EU.3.4.	Y	Y			
ASTRail	ASTRail - SAtellite-based Signalling and Automation SysTems on Railways along with Formal Method and Moving Block validation	2017-2019	H2020-EU.3.4.		Y			
AUTOC-ITS	Regulation Study for Interoperability in the Adoption of Autonomous Driving in European Urban Nodes	2016-2018	CEF					Y
Autodrive	Autodrive	2017-2020	H2020-EU.2.1.		Y	Y		
AutoMat	Automotive Big Data Marketplace for Innovative Cross-sectorial Vehicle Data Services	2014-2018	H2020-EU.2.1.			Y		
AutoMate	Automation as accepted and trustful teamMate to enhance traffic safety and efficiency	2016-2019	H2020-EU.3.4.			Y		

AUTONET 2030	Co-operative Systems in Support of Networked Automated Driving by 2030	2013-2016	FP7-ICT		Y	Y		
AUTOPACE	AUTOMATION PACE	2016-2018	H2020-EU.3.4.				Y	
AUTOPILOT	AUTOmated driving Progressed by Internet Of Things	2017-2019	H2020-EU.2.1.	Y	Y			
AutoPro	An adaptive system for modular automotive production to boost efficiency and reduce manufacturing cost.	2017-2017	H2020-EU.3.4.		Y	Y		
AUTOSHIP	Autonomous Shipping Initiative for European Waters	2019-2022	H2020-EU.3.4.			Y		
AVENUE	Autonomous Vehicles to Evolve to a New Urban Experience	2018-2022	H2020-EU.3.4.				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			
BRAINFLIGHT	Brain controlled aircraft flight using multiple feedback mechanisms	2012-2014	FP7-TRANSPORT			Y		
BRAVE	BRidging gaps for the adoption of Automated VEhicles	2017-2020	H2020-EU.3.4.	Y			Y	
CALITO	CAbin LIning auTOmation	2017-2020	H2020-EU.3.4.			Y		

CAPITAL	Collaborative cApacity Programme on ITS Training-educAtion and Liaison	2016-2019	H2020-EU.3.4.				Y	
CARGO-ANTS	Cargo handling by Automated Next generation Transportation Systems for ports and terminals	2013-2016	FP7-TRANSPORT		Y			
CarNet	Rapid Data Communication Network for Connected Cars	2015-2017	H2020-EU.3.4.	Y				
CARTRE	Coordination of Automated Road Transport Deployment for Europe	2016-2018	H2020-EU.3.4.				Y	
CASCADE	Model-based Cooperative and Adaptive Ship-based Context Aware Design	2013-2015	FP7-TRANSPORT			Y		
CB Container SpeedUp	Conexbird Wind speed up containers and prevent damages	2015-2016	H2020-EU.3.4.			Y		
CIMEC	Cooperative ITS for Mobility in European Cities	2015-2017	H2020-EU.3.4.				Y	
CITRUS	C-ITS for Trucks	2016-2019	CEF			Y		Y
CITY-HUB	City-Hub	2012-2015	FP7-TRANSPORT					Y
CITYMOBIL2	Cities demonstrating cybernetic mobility	2012-2016	FP7-TRANSPORT					Y
CIVITAS CAPITAL	CIVITAS CAPITAL - making the best of CIVITAS!	2013-2016	FP7-TRANSPORT				Y	
CLEV	Most cost and time efficient EU-wide cross-border automated parcel delivery solution	2015-2015	H2020-EU.3.4.			Y		

Cloud LSVA	Cloud Large Scale Video Analysis	2016-2018	H2020-EU.2.1.			Y		
Cloud Your Car UBI	Establishing new eco-driving methods to score drivers and to enhance good driving habits based on advanced analytical B2B software platform for Connected Cars.	2016-2016	H2020-EU.3.4.			Y		
C-MobILE	Accelerating C-ITS Mobility Innovation and depLoyment in Europe	2017-2020	H2020-EU.3.4.				Y	Y
Co2Team	Cognitive Collaboration for Teaming	2019-2021	H2020-EU.3.4.			Y		
CODECS	COoperative ITS DEployment Coordination Support	2015-2018	H2020-EU.3.4.				Y	
CoEXist	'AV-Ready' transport models and road infrastructure for the coexistence of automated and conventional vehicles	2017-2020	H2020-EU.3.4.			Y		Y
COLOMBO	Cooperative Self-Organizing System for low Carbon Mobility at low Penetration Rates	2012-2015	FP7-ICT		Y			
COMPANION	Cooperative dynamic formation of platoons for safe and energy-optimized goods transportation	2013-2016	FP7-ICT			Y		
CONCORDA	Connected Corridor for Driving Automation	2017-2020	CEF		Y			

CONNECTA	CONtributing to Shift2Rail's NExt generation of high Capable and safe TCMS and brAkes. Phase 1.	2016-2018	H2020-EU.3.4.			Y		
CONSORTIS	Concealed Objects Stand-Off Real-time Imaging for Security	2014-2017	FP7-SECURITY					Y
CORDIAL	Collaborative OWA robots for drilling and fasteners insertion in assembly lines	2017-2020	H2020-EU.3.4.	Y		Y		
CORUS	Concept of Operations for EuRopean UTM Systems	2017-2019	H2020-EU.3.4.		Y		Y	
Corvid	AI-based autonomous flight control for the electric passenger aircraft of the nearest future	2017-2018	H2020-EU.3.4.			Y		
C-Roads Austria	C-Roads Austria	2016-2020	CEF		Y			Y
C-Roads Belgium/Flanders	C-Roads Belgium/Flanders	2016-2020	CEF		Y			Y
C-Roads Belgium/Wallonia	C-Roads Belgium/Wallonia	2017-2020	CEF		Y			Y
C-Roads Czech Republic	C-Roads Czech Republic	2016-2020	CEF		Y			Y
C-ROADS France	C-ROADS France	2016-2020	CEF		Y			Y
C-ROADS Hungary	C-ROADS Hungary	2017-2020	CEF		Y			Y

C-ROADS ITALY	C-ROADS ITALY	2017-2020	CEF		Y			Y
C-ROADS PORTUGAL	C-ROADS PORTUGAL	2017-2020	CEF		Y			Y
C-Roads Slovenia 2	C-Roads Slovenia 2	2017-2020	CEF		Y			Y
C-Roads Spain	C-Roads Spain	2017-2020	CEF		Y			Y
C-Roads-Germany	C-Roads-Germany	2016-2020	CEF		Y			Y
CYCLADES	Crew-centered Design and Operations of ships and ship systems	2012-2015	FP7-TRANSPORT				Y	
CYRail	Cybersecurity in the RAILway sector	2016-2018	H2020-EU.3.4.		Y		Y	
DENSE	aDverse wEather eNvironmental Sensing systEm	2016-2019	H2020-EU.2.1.	Y				
DETECTOR	Detection, Evaluation and Characterisation of Threats to Road applications	2012-2013	FP7-TRANSPORT		Y			
DIAMOND	Revealing fair and actionable knowledge from data to support women’s inclusion in transport systems	2018-2021	H2020-EU.3.4.			Y	Y	
DORA	Door to Door Information for Airports and Airlines	2015-2018	H2020-EU.3.4.		Y		Y	
DREAMS	DRone European AIM Study	2017-2019	H2020-EU.3.4.		Y			

DRIVER GLASS	Terrestrial Traffic Mixed Reality Navigation	2017-2018	H2020-EU.3.4.			Y		
DriveToTheFutu re	Needs, wants and behaviour of 'Drivers' and automated vehicle users today and into the future	2019-2022	H2020-EU.3.4.			Y		Y
DroC2om	Drone Critical Communications	2017-2019	H2020-EU.3.4.			Y		
Easy-OBU	Enhanced (EGNOS/EDAS) Accuracy SYstem with GNSS Outage Bridging Unit	2012-2014	FP7-TRANSPORT		Y			
e-Awake	New Generation ADAS for Enhanced Driving Experience	2015-2016	H2020-EU.3.4.	Y				
EBSF_2	European Bus Systems of the Future 2	2015-2018	H2020-EU.3.4.					Y
ECO-FEV	Efficient Cooperative infrastructure for Fully Electric Vehicles	2012-2015	FP7-ICT			Y	Y	
EfficienSea 2	EfficienSea 2 - Efficient, Safe and Sustainable Traffic at Sea	2015-2018	H2020-EU.3.4.		Y		Y	
ELEMED	ELectrification of the Eastern MEDiterranean area (use of Cold Ironing and electricity as a propulsion alternative)	2016-2018	CEF					Y
ELIRAD	Everyday Life Radar Sensors For Transportation	2016-2018	H2020-EU.3.4.	Y				
EMAR	e-Maritime Strategic Framework and Simulation based Validation	2012-2014	FP7-TRANSPORT				Y	

ENABLE-S3	European Initiative to Enable Validation for Highly Automated Safe and Secure Systems	2016-2019	H2020-EU.2.1.					Y
ENDURUNS	Development and demonstration of a long-endurance sea surveying autonomous unmanned vehicle with gliding capability powered by hydrogen fuel cell	2018-2022	H2020-EU.3.4.					Y
ENSEMBLE	ENabling SafE Multi-Brand pLatooning for Europe	2018-2021	H2020-EU.3.4.		Y			
E-PILOTS	Evolution of cockPIt operations Levering on cOgnitive compuTing Services	2019-2021	H2020-EU.3.4.				Y	
ESPRIT	Easily diStributed Personal RapId Transit	2015-2018	H2020-EU.3.4.					Y
ESSI	Developing the EFAS Smart Services Initiative to introduce a game -changer in the digital tachograph market	2016-2017	H2020-EU.3.4.	Y				
EuTravel	Optimodal European Travel Ecosystem	2015-2017	H2020-EU.3.4.			Y		
EVA	SMART CITY NAVIGATION TOOL FOR THE VISUALLY IMPAIRED	2017-2017	H2020-EU.3.4.			Y	Y	
EVOLUTION	The Electric Vehicle revOLUTION enabled by advanced materials highly hybridized into lightweight components for easy integration and dismantling providing a reduced life cycle cost logic	2012-2016	FP7-NMP					Y

Fair Stations	Future Secure and Accessible Rail Stations	2017-2019	H2020-EU.3.4.			Y		
FAST-TRACKS	Fast rAdio technologieS for uninterrupTed TRAin to traCKside communications	2015-2016	H2020-EU.3.4.			Y		
FAST-TRACKS 2	Fast rAdio technologieS for uninterrupTed TRAin to traCKside communicationS (2)	2017-2019	H2020-EU.3.4.			Y		
FilGAPP	Filling the gap in GNSS Advanced Procedures and oPerations	2012-2014	FP7-TRANSPORT		Y			
FluidER	Real time Optoelectronic Sensors for Electro-Actuator Hydraulic Fluid Contamination Monitoring	2019-2021	H2020-EU.3.4.	Y				
FOT-Net Data	Field Operational Test Networking and Data Sharing Support	2014-2016	FP7-ICT			Y		
GAIN	GAIN - Galileo for Interactive Driving	2012-2014	FP7-TRANSPORT		Y			
GALAHD	General and Light Aviation Head-up Display	2016-2016	H2020-EU.3.4.			Y		
GECKO	Governance principles and mEthods enabling deCision maKers to manage and regulate the changing mObility systems	2018-2021	H2020-EU.3.4.				Y	
General Purpose DP	A Compact Dynamic Positioning System of General Purpose for Marine Units, Crafts and Ships	2014-2015	H2020-EU.3.4.	Y				

GRADE	GNSS Solutions for Increased GA and Rotorcraft Airport Accessibility Demonstration	2018-2019	H2020-EU.3.4.					Y
H2H	EGNSS Hull-to-Hull	2017-2020	H2020-EU.3.4.		Y			
HARVEST	Hierarchical multifunctional composites with thermoelectrically powered autonomous structural health monitoring for the aviation industry	2018-2021	H2020-EU.3.4.	Y	Y			
HCR	Market maturation of the first on-board autonomous biofouling cleaning system to keep ship’s hull clean at all times	2018-2020	H2020-EU.2.1.	Y				
HEADSTART	HARMONISED EUROPEAN SOLUTIONS FOR TESTING AUTOMATED ROAD TRANSPORT	2019-2021	H2020-EU.3.4.		Y			Y
HF AUTO	Human Factors of Automated Driving	2013-2017	FP7-PEOPLE				Y	
HIGHTS	High precision positioning for cooperative ITS applications	2015-2018	H2020-EU.3.4.	Y		Y		
i2D	i2D - intelligence to drive	2015-2015	H2020-EU.3.4.			Y		
ICARUS	Innovative changes in Air Transport. Research for Universally Designed Services	2012-2014	FP7-AAT				Y	
ICOMPOSE	Integrated Control of Multiple-Motor and Multiple-Storage Fully Electric Vehicles	2013-2016	FP7-ICT		Y			

ICT4CART	ICT Infrastructure for Connected and Automated Road Transport	2018-2021	H2020-EU.3.4.			Y		
i-GAME	Interoperable GCDC AutoMation Experience	2013-2016	FP7-ICT		Y	Y		
I-GOing	Setting the path for mass market use of Indoor Galileo Operations	2012-2014	FP7-TRANSPORT		Y			
InDrive	InDrive : Automotive EGNSS Receiver for High Integrity Applications on the Drive	2016-2017	H2020-EU.2.1.		Y			
INFRAMIX	Road Infrastructure ready for mixed vehicle traffic flows	2017-2020	H2020-EU.3.4.			Y		
interACT	Designing cooperative interaction of automated vehicles with other road users in mixed traffic environments	2017-2020	H2020-EU.3.4.			Y		
InterCor	InterCor	2016-2019	CEF					Y
INTRANSYS	Delivering next generation Transport Management System to European transport SMEs	2015-2015	H2020-EU.3.4.		Y			
INTRANSYS 2	Delivering next generation Transport Management System to European transport SMEs (2)	2016-2018	H2020-EU.3.4.		Y			
IT2RAIL	Information Technologies for Shift to Rail	2015-2017	H2020-EU.3.4.				Y	
iTractor	Smart farmer's assistant - iTractor ®	2016-2016	H2020-EU.3.4.			Y	Y	

ITS OBSERVATORY	ITS Observatory	2015-2017	H2020-EU.3.4.				Y	
Jam	Enhancing fuel efficiency and reducing vehicle maintenance and downtime costs, using real-time data from vehicle sensors (IoT) and a machine learning algorithm for big data analysis.	2016-2016	H2020-EU.3.4.	Y		Y		
JAM	JAM: vehicle predictive maintenance through Artificial Intelligence	2016-2018	H2020-EU.3.4.	Y		Y		
Joysteer 3.0	A New Drive-by-Wire Technology for People with Disabilities and Industrial Applications	2018-2018	H2020-EU.2.1.			Y		
L3Pilot	Piloting Automated Driving on European Roads	2017-2021	H2020-EU.3.4.					Y
LeMO	Leveraging Big Data to Manage Transport Operations	2017-2020	H2020-EU.3.4.			Y		
Levitate	Societal Level Impacts of Connected and Automated Vehicles	2018-2021	H2020-EU.3.4.				Y	
Logist-IoT	SensorToCloud Technologies for Loss Prevention and Smart Last Mile Logistics Operations	2017-2017	H2020-EU.3.4.	Y				
LoStPReCon	Long-term structural performance of pre-stressed concrete bridges: A risk-based monitoring informed framework for life-cycle asset management	2015-2017	H2020-EU.1.3.			Y		

M2I	M2I (Mobilité Integrée pour l'Ile-de-France)	2016-2019	CEF			Y		
MAGYCO	Mems based Appliance for GYro Compassing in general aviation and unmanned aircraft applications	2017-2017	H2020-EU.3.4.	Y				
MAVEN	Managing Automated Vehicles Enhances Network	2016-2019	H2020-EU.3.4.			Y		
MeBeSafe	Measures for behaving safely in traffic	2017-2020	H2020-EU.3.4.			Y		
MEDIATOR	MEdiating between Driver and Intelligent Automated Transport systems on Our Roads	2019-2023	H2020-EU.3.4.			Y		
MFDS	Multi-Functional Detective System (MFDS) Advanced, Intelligent Transport System creating smarter and safer European roads	2017-2017	H2020-EU.3.4.		Y			
MINIMA	MItigating Negative Impacts of Monitoring high levels of Automation	2016-2018	H2020-EU.3.4.		Y			
MODULUSHCA	Modular Logistics Units in Shared Co-modal Networks	2012-2016	FP7-TRANSPORT					Y
MOMENTUM	Modelling Emerging Transport Solutions for Urban Mobility	2019-2022	H2020-EU.3.4.			Y		
MUGICLOUD	PLUG AND PLAY intelligent transport system for bus and coach sector	2017-2018	H2020-EU.3.4.	Y	Y			

MultiFAL	Multifunctional automation system for Fuselage Assembly Line	2019-2022	H2020-EU.3.4.			Y		
MUNIN	Maritime Unmanned Navigation through Intelligence in Networks	2012-2015	FP7-TRANSPORT		Y			
NAFTI	Noise Abatement Fms with Tactile Interface	2017-2021	H2020-EU.3.4.			Y		
NAVDEC	Navigational Decision Support System for Improved COLREGs Safety Management	2015-2015	H2020-EU.3.4.		Y			
NAVISAS	Navigation of Airborne Vehicle with Integrated Space and Atomic Signals	2016-2017	H2020-EU.3.4.	Y	Y			
NEWBITS	NEW Business models for ITS	2016-2019	H2020-EU.3.4.				Y	
NICENAV	NICENAV Navigation-grade ITAR-free Certifiable Equipment for the Navigation of manned and unmanned Air Vehicle, based on FOG technology	2015-2015	H2020-EU.3.4.	Y				
NOESIS	NOvel Decision Support tool for Evaluating Strategic Big Data investments in Transport and Intelligent Mobility Services	2017-2019	H2020-EU.3.4.			Y		
NordicWay 2	NordicWay 2	2017-2020	CEF					Y
NOVIMAR	NOVel Iwt and MARitime transport concepts	2017-2021	H2020-EU.3.4.		Y			
NZi-VITAL	Novel Smart Motorcycle helmet with integrated health monitoring	2017-2017	H2020-EU.3.4.		Y			Y

	system, accident detection and eCall compliance.							
OMNISCIENT	Prediction and optimisation platform for the mobile assets management	2018-2018	H2020-EU.3.4.			Y		
OPTEPLA	Open OBDII Telematics Platform - OPTEPLA	2015-2015	H2020-EU.3.4.		Y			
OPTIMUM	Multi-source Big Data Fusion Driven Proactivity for Intelligent Mobility	2015-2018	H2020-EU.3.4.			Y		
OSCCAR	Future Occupant Safety for Crashes in Cars	2018-2021	H2020-EU.3.4.				Y	
PACS	Pantograph Active Control System for e-Highways	2017-2017	H2020-EU.3.4.	Y				
PANORAMIX	PANORAMIX: Platform for the operAtion aNd Optimization in ReAl-time of MIXed autonomous fleets	2018-2018	H2020-EU.3.4.		Y			
PANTERA	Pervasive Adoption of gNss Technologies in sEcuRity Application	2012-2014	FP7-TRANSPORT		Y			
PAsCAL	Enhance driver behaviour and Public Acceptance of Connected and Autonomous vehicLes	2019-2022	H2020-EU.3.4.				Y	
PercEvite	PercEvite - Sense and avoid technology for small drones	2017-2020	H2020-EU.3.4.	Y				
PJ10 PROSA	Controller Tools and Team Organisation for the Provision of	2016-2019	H2020-EU.3.4.		Y			

	Separation in Air Traffic Management							
PODIUM	Proving Operations of Drones with Initial UTM Management	2018-2019	H2020-EU.3.4.		Y			Y
PRoPART	Precise and Robust Positioning for Automated Road Transports	2017-2019	H2020-EU.3.4.	Y				Y
PROSPECT	PROactive Safety for PEdestrians and CyclisTs	2015-2018	H2020-EU.3.4.				Y	
PROXITRAK	PROXITRAK - next generation IoT tracking solution for a connected logistics - collect, analyse and visualise big data in a true real time	2017-2017	H2020-EU.3.4.			Y		
QualiSaR	Development of a Qualification Procedure for the Usage of Galileo Satellite Receivers for Safety Relevant Applications	2012-2014	FP7-TRANSPORT	Y	Y			
Railscope	Improving Railway Safety Through Innovative Sensor System	2017-2018	H2020-EU.3.4.	Y				
RCMS	Rethinking Container Management Systems	2015-2017	H2020-EU.3.4.			Y		Y
REALISE GroLaS	Runway independent automatic launch and landing system for civil UAV based on GroLaS	2015-2015	H2020-EU.3.4.			Y		
ReVeAL	Regulating Vehicle Access for improved Livability	2019-2022	H2020-EU.3.4.					Y
RobustSENSE	Robust and Reliable Environment Sensing and Situation Prediction	2015-2018	H2020-EU.2.1.	Y	Y			

	for Advanced Driver Assistance Systems and Automated Driving							
SAFE STRIP	Safe and green Sensor Technologies for self-explaining and forgiving Road Interactive aPplications	2017-2020	H2020-EU.3.4.	Y	Y			
SafeClouds.eu	Data-driven research addressing aviation safety intelligence	2016-2019	H2020-EU.3.4.		Y			
SafeShore	System for detection of Threat Agents in Maritime Border Environment	2016-2018	H2020-EU.3.7.				Y	
SATLOC	Satellite based operation and management of local low traffic lines (SATLOC)	2012-2014	FP7-TRANSPORT		Y			
SCOOP@F Part 2	SCOOP@F Part 2	2016-2018	CEF					Y
SCOUT	Safe and COnnected aUtomation in road Transport	2016-2018	H2020-EU.3.4.				Y	
SDO-MET	Automatic Rail Safety Solution	2015-2017	H2020-EU.3.4.		Y			
SEAHUB	Real-time Fleet Performance Center (FPC) to optimize energy efficiency in Maritime Transport to reduce fuel consumption and harmful emissions	2016-2017	H2020-EU.3.4.			Y		
SECOPS	An Integrated Security Concept for Drone Operations	2017-2019	H2020-EU.3.4.		Y			

SENSE	Accelerating the Path Towards Physical Internet	2017-2020	H2020-EU.3.4.		Y			
SIMPLI-CITY	SIMPLI-CITY The Road User Information System of the Future	2012-2015	FP7-ICT			Y	Y	
SIRENA	Novel electric stair climber to break barriers in transport of disabled people and goods through a safe, quick and comfortable movement	2018-2020	H2020-EU.2.1.				Y	
Skylynx	Upgrading Railways from the Air	2017-2017	H2020-EU.3.4.		Y			
SMART	Smart Automation of Rail Transport	2016-2019	H2020-EU.3.4.	Y				
SMARTCARS	Low cost Advanced Driver Assistance Systems (ADAS): A cost affordable solution for improved road safety	2016-2016	H2020-EU.3.4.	Y			Y	
SMARTCARS 2	Low Cost Advanced Driver Assistance Systems (ADAS): A cost affordable solution for improved road safety (2)	2017-2019	H2020-EU.3.4.	Y			Y	
SMARTER	Surveillance of Maritime Surroundings through Laser Technology	2015-2015	H2020-EU.3.4.	Y				
SMARTER-2	Surveillance of MARiTime surroundings through lasER technology (2)	2016-2018	H2020-EU.3.4.	Y				

SmartEye	The most accurate 3D scanner for boosting the uptake of automated guided vehicles (AGVs)	2018-2018	H2020-EU.2.1.		Y	Y		
SmarTrip	SMARt platform to optimise TRIP management	2016-2016	H2020-EU.3.4.			Y	Y	
SocialCar	SocialCar	2015-2018	H2020-EU.3.4.			Y		
SOCRATES 2.0	System of Coordinated Roadside and Automotive Services for Traffic Efficiency and Safety	2017-2020	CEF					Y
SolC-ITS	SOLRED C-ITS Monitoring Network	2016-2019	CEF		Y			
SPARTAN	Smart multilevel Power conditioning for AeRonautical elecTricAl uNits	2018-2021	H2020-EU.3.4.	Y				
STS	Motorcycle all-in-one smart tour integrated road security system	2017-2018	H2020-EU.3.4.		Y		Y	
SUaaVE	SUpporting acceptance of automated VEhicle	2019-2022	H2020-EU.3.4.				Y	
SUNRISE	Strengthening User Networks for Requirement Investigation and Supporting Entrepreneurship	2012-2015	FP7-TRANSPORT		Y			
TaCo	Take Control	2016-2018	H2020-EU.3.4.			Y		
TAXISAT	A new TAXI application guided by SATellite	2012-2014	FP7-TRANSPORT		Y			
TIMON	Enhanced real time services for an optimized multimodal mobility	2015-2018	H2020-EU.3.4.			Y		

	relying on cooperative networks and open data							
TransAID	Transition Areas for Infrastructure-Assisted Driving	2017-2020	H2020-EU.3.4.		Y			
TransSec	Autonomous emergency manoeuvring and movement monitoring for road transport security	2018-2021	H2020-EU.3.4.		Y			
Trustonomy	Building Acceptance and Trust in Autonomous Mobility	2019-2022	H2020-EU.3.4.				Y	Y
TrustVehicle	Improved trustworthiness and weather-independence of conditional automated vehicles in mixed traffic scenarios	2017-2020	H2020-EU.3.4.				Y	
ULTRA	Unmanned Aerial Systems in European Airspace	2012-2013	FP7-TRANSPORT				Y	
UnCoVer CPS	Unifying Control and Verification of Cyber-Physical Systems	2015-2018	H2020-EU.2.1.					Y
UNIFARM	GNSS User Forum on Navigation based Innovation for Farmers	2012-2014	FP7-TRANSPORT		Y			
UP-Drive	UP-Drive : Automated Urban Parking and Driving	2016-2018	H2020-EU.2.1.	Y				
USIS	U-Space Initial Services	2018-2019	H2020-EU.3.4.		Y			
V-Charge	V-Charge - Autonomous Valet Parking and Charging for e-Mobility	2011-2015	FP7-ICT					Y

VDRConnect	VDRConnect: VDR-based vessel telematics solution	2016-2016	H2020-EU.3.4.		Y			
VI-DAS	Vision Inspired Driver Assistance Systems	2016-2019	H2020-EU.3.4.	Y	Y			
VISTA	Vision-based Inspection Systems for automated Testing of Aircraft interiors	2018-2020	H2020-EU.3.4.	Y		Y		
VRA	Support action for Vehicle and Road Automation network	2013-2016	FP7-ICT	Y			Y	
WiiGO	An autonomous, self-driven robot system to improve the mobility and integration of people, creating a more equal and accessible society	2018-2018	H2020-EU.2.1.				Y	Y
WINFRAME 4.0	Full scale innovative composite windows frames for Regional Aircraft fuselage barrel on-ground demonstrators	2018-2020	H2020-EU.3.4.			Y		Y
X2Rail-1	Start-up activities for Advanced Signalling and Automation Systems	2016-2019	H2020-EU.3.4.		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	H2020-EU.3.4.		Y			

Annex 2: Scopus database regular expression analysis keywords

Search restricted to journal articles

Keywords used for full database assembly:

“autonomous vehicle”

“driverless”

“unmanned”

Search period:

January 2000 to December 2020

Keywords used for all subthemes filtering:

"aircraft"

"train"

"car"

"vehicle"

"ship"

Keywords for Connectivity and safety:

'connectivity', 'safety', 'v2v', 'v2i', 'network'

Keywords for On-board equipment:

'adas','sensor','on-board'

Keywords for Supporting infrastructure:

'infrastructure','flight control', "predictive maintenance"

Keywords for Largescale testing:

'testing', "large scale", 'demonstration'

Keywords for Socio-economic impacts and human factors:

'social', 'accessibility'

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