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New and Emerging Transport Technologies and Trends in European Research and Innovation Projects

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

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Contents

Abstract

Research and innovation (R&I) have a significant role in the development of transport systems. This report provides a comprehensive assessment of 20 technologies from European R&I projects, researched at a low development phase, that have received high levels of funding and for which the number of organisations involved (and projects) indicate a high level of interest and capability in developing the technologies further. The assessment follows the methodology developed by the European Commission's Transport Research and Innovation Monitoring and Information System (TRIMIS). The report critically assesses the development of the technologies to date, their potential applications and impact, as well as their alignment with European policies. It also provides an outlook of technologies researched at higher development phases, and indications on current global research trends and intellectual property activity.

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Executive summary

The report presents a comprehensive analysis of a selection of transport technologies from European Union (EU) funded research and innovation (R&I) projects. It identifies the potential application and impact of the technologies, together with the relevant policy context and market activity in Europe.

Policy context

The European Commission's (EC) 2011 White Paper on Transport[1] highlights 40 concrete initiatives for the next decade to build a competitive transport system that will increase mobility, remove major barriers in key areas and fuel growth and employment, and reduce Europe's dependence on imported oil and cut greenhouse gas (GHG) emissions of transport by 60% by 2050. An evaluation of the White Paper is still ongoing aiming to examine all areas where it made policy proposals[2]. In May 2017, the EC adopted the Strategic Transport Research and Innovation Agenda (STRIA) as part of the 'Europe on the Move' package, which highlights key transport R&I areas and priorities for clean, connected and competitive mobility[3]. STRIA includes seven roadmaps on seven transport priority areas, aiming at a more integrated and effective transport system across Europe and to make better use of innovation and new technologies in transport. In May 2018, the EC published 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.[4] The European Green Deal[5] presented in 2019 defines a target of decreasing GHG emissions by up to 90% by 2050, where transport R&I actions are key to support achieving this objective.

The analyses included in this report focus on EU funded R&I projects and aim to highlight some of the new and emerging technologies and trends in the transport sector and are based on the European Commission's Transport Research and Innovation Monitoring and Information System (TRIMIS).

The contribution of the highlighted technologies to European transport policy objectives – including the European Green Deal's decarbonisation targets – is detailed in the policy alignment sections.

Main findings and conclusions

Focusing on selected EU funded projects, this report presents an analysis of transport technologies researched in the last years at a low phase of development. In addition, the report includes a review of a selected limited number of technologies at a high phase of development, identifying technologies that are likely to have an impact on products and operations in the short to medium term, and illustrating some that may contribute to products and systems that will be available in the shorter term.

With regard to the support of the assessed low development phase technologies to EU transport policies, the main findings grouped according to transport modes are the following:

On aviation:

- **Smart sensors and smart running gear components for self-diagnosis** can contribute to the achievement of the 2011 White Paper goal of a modernised air traffic management infrastructure with a much more efficient air traffic management.
- The increased fuel efficiency of **ultra-high bypass ratio and pressure ratio** aircraft engines and the weight reductions using predictive virtual testing of composite structures up to failure and of nanomaterials for structural health monitoring will contribute to meeting the EU targets of a 90% reduction in transport GHG emissions by 2050 and improvements in air quality around airports.
- The **hybrid laminar flow control** technology can help reach the targets of 40% low-carbon sustainable fuels in aviation of the 2011 White Paper and the European Green Deal's aim of 90% reduction in transport emissions by 2050.

[1] European Commission (2011), WHITE PAPER Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system COM/2011/0144 final; European Commission: Brussels

[2] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/2080-Evaluation-of-the-2011-White-Paper-on-Transport

[3] 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.

[4] Europe on the move - Sustainable Mobility for Europe: safe, connected, and clean COM/2018/293 final, (European Commission, 2018)

[5] European Commission (2019), The European Green Deal COM/2019/640 final; European Commission: Brussels

- **Safety (and maintenance) improvement through automated flight data analysis** and **collision avoidance system** can also improve the safety of aircraft, a key goal in the Single European Sky (SES) initiative which looks at improving safety by a factor of 10.

On rail:

- The **on-board testing systems for ETCS (European Train Control System)** technology capacity improvements will benefit the rail freight sector and will contribute to the European Green Deal policy objective of freight modal shift from road to rail.

On road transport:

- The introduction of **mobile CNG fuelling stations** will help achieve greater CNG distribution, in line with the requirements of the alternative fuels infrastructure directive for availability of an appropriate number of CNG refuelling points in urban/suburban and other densely populated areas along the TEN-T core network by 2025, and will help towards the ramp up and deployment of sustainable alternative transport fuels, thus contributing towards meeting the goal included in the European Green Deal. However, to gain the full benefits of using CNG as a fuel, from the extraction to the powering of vehicles, research will need to be conducted into production methods that include carbon-neutral natural gas (or methane).
- **Open platform concept for mobility services** has the ability to support sustainable urban mobility plans (SUMPs), which are in-line with the EU policy on improving air quality, reducing congestion and reducing CO_2 emissions from transport.
- The efficiency delivered by **truck platooning** supports the EU policy to develop smart systems for traffic management, which will improve transport cooperativity and connectivity and with the Europe on the Move policy, which aims to have automated driving on motorways (in particular truck platooning) within the 2020s, moving towards full autonomous mobility in the 2030s.
- **Battery management system (BMS) modules** could increase the attractiveness of new and older BEVs; helping to remove conventionally fuelled vehicles from the road, and help achieve CO_2 reduction targets for new cars and vans in line with the performance standards for cars and vans post-2020 policy, due to the zero CO_2 tailpipe emissions from BEVs.
- **EV component modelling tools** could allow for an improved time-to-market for electric vehicles, and hence accelerate their market uptake in Europe. This will help towards the policy goal of reducing 'conventionally-fuelled' cars in urban transport and provide a route for road transport decarbonisation.
- **Hydrogen storage systems** will help with the attractiveness of hydrogen powered vehicles in all transport modes and help to achieve cleaner air, particularly in urban areas.
- **Vehicle energy management systems** can increase the attractiveness of electric vehicles by offering a higher real-world driving range when using climate control; the subsequent increased use of electric vehicles will help to reduce the amount of air pollution in urban areas.

On waterborne transport:

- **Holistic life cycle performance assessment methods** and **electric propulsion system for vessels** will help achieve the 2011 White Paper's goal of reducing EU CO_2 emissions from maritime bunker fuels by 40% and can also help with the European Green Deal aims to reduce pollution in EU ports.
- With more efficient shipping routes and information provided to guide sustainable policies, **computer simulations modelling climatic impact on Arctic marine transportation**, can contribute to reducing overall GHG emissions by 90%, as targeted in the European Green Deal, while, with more accurate simulations on the climate, better choices can be made in protecting and preserving it, in line with the 2016 EU Arctic policy.
- **Electric ferry** can help reduce EU CO_2 emissions from maritime bunker fuels, supporting also the European Green Deal objectives of reducing transport emissions and a shift from road to inland waterway freight, as well as the reduction in pollution of EU ports.
- **Evacuation model validation data sets** has parallels to moving close to zero fatalities by 2050. This technology currently focuses on reducing casualties and fatalities in waterborne transport rather than road but there is some potential for the sensor and live information technology to carry down to road use.

From the review of a selected limited number of technologies at a high development phase, relevant findings show:

- **Public charging infrastructure** technologies provide a means of charging electric vehicles and can help with introducing a minimum level of infrastructure for charging electric vehicles across the EU at one public charging point for every ten electric vehicles, in line with the Alternative Fuels Infrastructure (AFI) directive's requirements.
- **Hydrogen production and refuelling** technologies that concern hydrogen as a transport fuel and have a higher development phase (i.e. more mature technologies), include the production of hydrogen using an electrolyser system and the refuelling of hydrogen by use of an ionic compressor. These technologies can help towards the goal of increasing hydrogen account on the final energy demand across all sectors within Europe.
- **Cockpit-based technologies for improved pilot workflow** are a group of technologies which aim to reduce pilots' peak workload and support them in dealing with difficult situations, thus enhancing safety and performance. With an average of 24 yearly fatalities in commercial flights across the period 2010-2018, there is still a clear need for advances in cockpit-based technologies for improved pilot workflow.
- **ICT support systems for multimodality** technologies are used to bring multiple benefits to public organisations by providing real-time visibility, efficient data exchange and better flexibility to react to unexpected changes along the route. Future developments in this technology are focused on using big data and the IoT (Internet of Things) to develop machine-learning models to predict freight movements and improve multimodal operations. The use of an IoT network could provide much more accurate real-time data, allowing for multimodal logistics operators to optimise the supply chain and reduce overall delays in the transportation of goods.

These findings can help stakeholders in inducing transport innovation, including policy makers, regulators, transport service providers, and standardisation bodies. Furthermore, insights into the current status of these technologies and arising future needs help the STRIA Working Groups (WGs) to better assess R&I activities.

Related and future JRC work

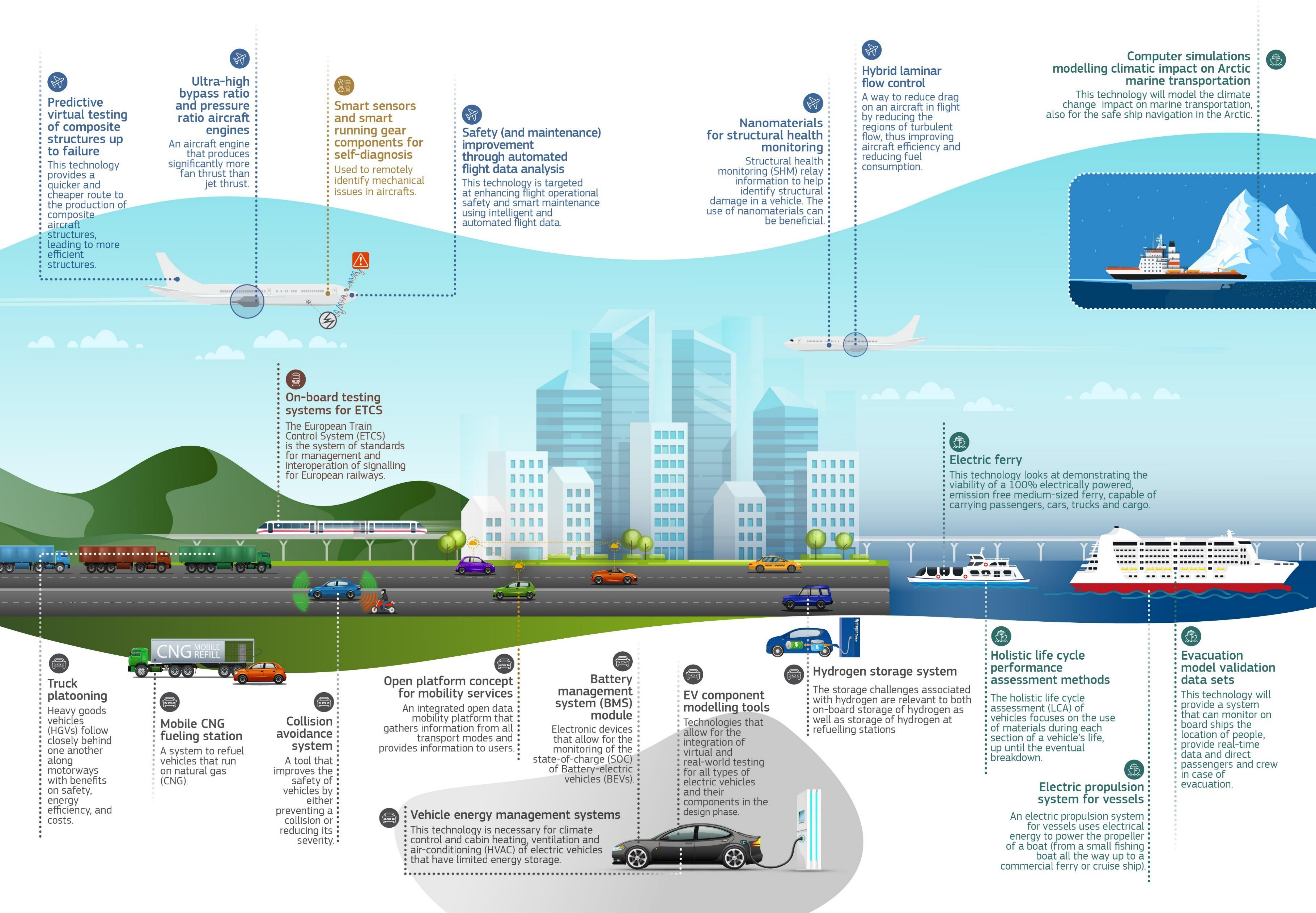
The TRIMIS team is consolidating and expanding the data repository to better assess R&I efforts of projects not funded by the EU or Member States. As part of this effort, additional information on patents and academic publications will be added. TRIMIS, based on its research, provides recommendations to policymakers, and will continue to provide support to STRIA and transport innovation at large. It does so by publishing thematic reports on the seven STRIA roadmaps, ad hoc reports, and other policy outputs (i.e. Science for Policy briefs). The developed methodologies on horizon scanning and on the identification, inventory and assessment of new and emerging technologies provide the background for this report.

Quick guide

The report is structured as follows:

Section 1 gives a brief introduction. Section 2 provides the methodological background and the scope of this report. Section 3 analyses the 20 identified technologies at a low development phase. Section 4 highlights trends in patent analysis and scientific research linked to these technologies. Section 5 analyses five technologies at a high development phase. Finally, Section 6 provides the conclusions.

The figure on the next page provides a quick overview of the 20 technologies researched at a lower development phase and their link to different transport modes (including multiple modes) in the form of an infographic.


Predictive virtual testing of composite structures up to failure
This technology provides a quicker and cheaper route to the production of composite aircraft structures, leading to more efficient structures.
Ultra-high bypass ratio and pressure ratio aircraft engines
An aircraft engine that produces significantly more fan thrust than jet thrust.
Smart sensors and smart running gear components for self-diagnosis
Used to remotely identify mechanical issues in aircrafts.
Safety (and maintenance) improvement through automated flight data analysis
This technology is targeted at enhancing flight operational safety and smart maintenance using intelligent and automated flight data.
Nanomaterials for structural health monitoring
Structural health monitoring (SHM) relay information to help identify structural damage in a vehicle. The use of nanomaterials can be beneficial.
Hybrid laminar flow control
A way to reduce drag on an aircraft in flight by reducing the regions of turbulent flow, thus improving aircraft efficiency and reducing fuel consumption.
Computer simulations modelling climatic impact on Arctic marine transportation
This technology will model the climate change impact on marine transportation, also for the safe ship navigation in the Arctic.
On-board testing systems for ETCS
The European Train Control System (ETCS) is the system of standards for management and interoperation of signalling for European railways.
Electric ferry
This technology looks at demonstrating the viability of a 100% electrically powered, emission free medium-sized ferry, capable of carrying passengers, cars, trucks and cargo.
CNG MOBILE REFILL
Truck platooning
Heavy goods vehicles (HGVs) follow closely behind one another along motorways with benefits on safety, energy efficiency, and costs.
Mobile CNG fueling station
A system to refuel vehicles that run on natural gas (CNG).
Collision avoidance system
A tool that improves the safety of vehicles by either preventing a collision or reducing its severity.
Open platform concept for mobility services
An integrated open data mobility platform that gathers information from all transport modes and provides information to users.
Battery management system (BMS) module
Electronic devices that allow for the monitoring of the state-of-charge (SOC) of Battery-electric vehicles (BEVs).
EV component modelling tools
Technologies that allow for the integration of virtual and real-world testing for all types of electric vehicles and their components in the design phase.
Hydrogen storage system
The storage challenges associated with hydrogen are relevant to both on-board storage of hydrogen as well as storage of hydrogen at refuelling stations
Holistic life cycle performance assessment methods
The holistic life cycle assessment (LCA) of vehicles focuses on the use of materials during each section of a vehicle's life, up until the eventual breakdown.
Evacuation model validation data sets
This technology will provide a system that can monitor on board ships the location of people, provide real-time data and direct passengers and crew in case of evacuation.
Electric propulsion system for vessels
An electric propulsion system for vessels uses electrical energy to power the propeller of a boat (from a small fishing boat all the way up to a commercial ferry or cruise ship).
Vehicle energy management systems
This technology is necessary for climate control and cabin heating, ventilation and air-conditioning (HVAC) of electric vehicles that have limited energy storage.

1 Introduction

Technological developments are fundamental in order for the transport sector to address current and future socio-economic challenges, also considering the ever-changing, complex and competitive world we live in. These developments will be achieved through research and innovation (R&I), which allows new quality standards in relation to the mobility of people and goods.

The technological applications across the various transportation systems and subsystems have been increasing in numbers and level of complexity along with the overall technological development in related sectors (Energy, Information and Communication Technology, etc.). The assessment of new and emerging transport technologies and trends is challenging, since often their performance can be tested only in virtual conditions and without consistent information of their potential use.

The European Commission's (EC) 2011 White Paper (European Commission, 2011) highlights 40 concrete initiatives for the next decade to build a competitive transport system that will increase mobility, remove major barriers in key areas and fuel growth and employment, and reduce Europe's dependence on imported oil and cut carbon emissions in transport by 60% by 2050. An evaluation of the White Paper is still ongoing aiming to examine all areas where it made policy proposals.

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

In May 2018, the EC published 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 (European Commission, 2018).

The European Green Deal seeks a 90% reduction in emissions by 2050 (European Commission, 2019). Since transport currently accounts for a quarter of the EU's greenhouse gas emissions, and this figure continues to rise as demand grows, boosting considerably the uptake of clean vehicles and alternative fuels and moving to more sustainable transport in general, will help meet this objective.

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:

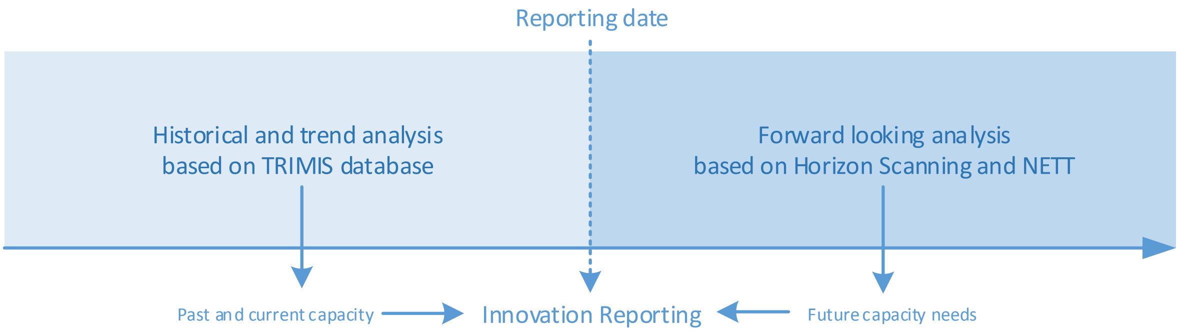
- Connected and automated transport (CAT);
- Transport electrification (ELT);
- Vehicle design and manufacturing (VDM);
- Low-emission alternative energy for transport (ALT);
- Network and traffic management systems (NTM);
- Smart mobility and services (SMO);
- Transport infrastructure (INF).

An effective monitoring and information mechanism must support the implementation of STRIA. The ECs 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, and develop analytical tools on the European transport system (Tsakalidis et al. 2018). TRIMIS was funded under the Horizon 2020 Work Programme 2016-2017 on Smart, Green and Integrated transport (European Commission, 2017c).

Contrary to other transport policy-support tools, TRIMIS provides an integrated approach to bring socio-economic figures and strategic foresight together, fostering a bidirectional monitoring and assessment of transport innovation. This monitoring and assessment is both backward looking, using historic trend analysis, but also forward looking, through the use of strategic foresight and the development of an inventory on new and emerging technologies and trends (NETTs) in transport (Tsakalidis et al. 2020a).

Figure 1 schematically presents the bidirectional monitoring and assessment approach of TRIMIS.

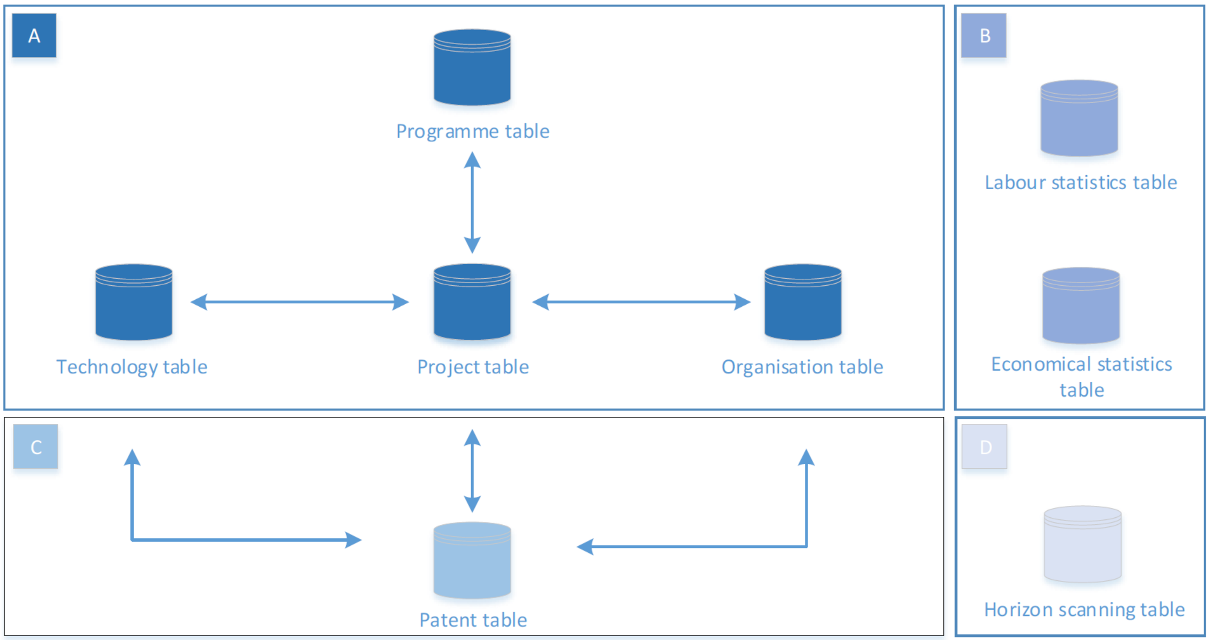
Figure 1. TRIMIS bidirectional monitoring and assessment approach.



Source: Tsakalidis et al. 2020a

The central element of TRIMIS is its database, a relational database that incorporates information on several transport R&I dimensions (van Balen et al. 2019). **Figure 2** presents the TRIMIS database structure, highlighting four different fields (A, B, C, D) with eight different tables (project table, programme table, technology table, organisation table, labour statistics table, economic statistics table, patent table, horizon scanning table). The database structure provides an insight into TRIMIS' current and future analytical capabilities.

Figure 2. TRIMIS database structure.



Source: van Balen et al. 2019

Building on the database, the previously mentioned forward looking transport technology monitoring and assessment of TRIMIS is addressed within the task of horizon scanning (Tsakalidis et al. 2019) and the creation of an inventory and regular reporting on NETTs in the transport sector (Gkoumas et al. 2018).

Horizon scanning in TRIMIS is applied through a structured and systematic collaborative exercise that contributes to the identification of NETTs, with a potential future impact on the transport sector (Tsakalidis et al. 2020b), while supporting the assessment of current and future research needs and providing transport related insights to the broader European Commission foresight system, thus, contributing to a higher-level strategic framework also covering the transport domain.

The creation of an inventory and regular reporting on NETTs in the transport sector, the topic of this report, focuses on technologies researched in projects from the TRIMIS database, which are then assessed for their innovation potential. Until now, an effort has been made within TRIMIS to identify all technologies researched in FP projects since 2007 and build a technology database based on a hierarchic taxonomy (Gkoumas and Tsakalidis, 2019). Initial results from this exercise were presented in a JRC Science for Policy brief in May 2019[6]. The developed database table currently includes technologies allocated under overarching technology themes, researched in EU funded projects since 2007. It also includes a limited number of technologies identified from Member State-funded projects in the TRIMIS database. All technologies have been assessed for their development phase - from low (research or validation) to high (demonstration or implementation). Furthermore, technology metrics are linked with organisational data, with the scope to identify and assess technology value chains (Tsakalidis et al. 2020c).

Relevant outputs from this technology identification and assessment are found in the TRIMIS assessment reports, which include a comprehensive analysis of selected R&I projects financed by the 7th Framework Programme (FP7) and the Horizon 2020 (H2020) Framework Programme (FP), relevant to the seven STRIA roadmaps on INF and CAT (Gkoumas, et al., 2019a, 2019b), ALT and VDM (Ortega Hortelano et al., 2019; 2020), SMO and NTM (Tsakalidis et al. 2020d, 2020e) and NTM (van Balen et al., 2020).

Building on the previous work by TRIMIS on building an inventory of transport technologies, this report assesses a selection of 20 transport technologies researched at a low development phase, that have received the highest funding in FPs and for which the number of organisations involved (and projects) indicate a high level of interest and capability in developing the technologies further. The aim is to give an early warning of potentially disruptive technologies and help guide the development of future research priorities and policies. The report critically assesses the development of the technologies to date, their potential applications and impact, as well as their alignment with European policies. The analyses are integrated with findings from the Scopus research database and the TRIMIS patent database that highlight research and innovation trends in the private sector worldwide.

In addition, the report includes a focused review of a selected number of technologies (5) at a high development phase, identifying technologies that are likely to have an impact on products and operations in the short to medium term, and illustrating some that may contribute to products and systems that will be available in the shorter term.

The assessment of this technological development gains greater importance, considering the ambition to make *Europe fit for the digital age* and in line with the sustainability goals of the *European Green Deal* (European Commission, 2020).

Findings can help stakeholders in the field of transport innovation, including policy makers, regulators, transport service providers, and standardisation bodies. Furthermore, insights related to the current status and future needs helps the STRIA Governance Group to better assess R&I activities.

[6] https://trimis.ec.europa.eu/content/assessing-new-and-emerging-transport-technologies-identifying-opportunities-innovation

2 Methodological background

The main goal of this report is to thoroughly review NETTs from EU-funded projects. To this aim, the following actions were necessary:

1. The development and consolidation of the TRIMIS database of programmes and projects.
2. The development of a methodology for the identification and assessment of technologies researched within R&I projects.
3. The development of a methodology for the Intellectual Property (IP) analysis.
4. The development of a methodology for scientific research analysis.

A description of these steps is provided in the following sections.

2.1 Database development and labelling

TRIMIS contains a continuously updated database of EU and MS funded programmes and projects (currently over 7,500) on transport R&I. Projects funded by the European FPs are retrieved through an automated data link with the Community Research and Development Information Service (CORDIS), while projects funded by MSs are inserted manually by national contact points, but also by TRIMIS users on a voluntary basis. Project inputs are then evaluated and labelled according to a series of criteria linked to the STRIA roadmap classification and the technologies they research, and then added to the database and published on the TRIMIS web platform (van Balen et al., 2019).

2.2 Identification and assessment of the technologies researched within Framework Programmes

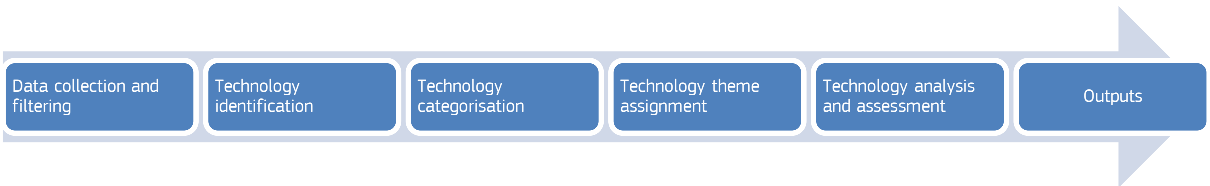
A comprehensive methodology has been established within TRIMIS, which led to the identification of the technologies developed by projects funded under FP7 and H2020. The technologies were assigned to themes, to facilitate the comparison and analysis of various fields of transport innovation.

2.2.1 Technological assessment of EU projects

The TRIMIS technology analysis currently focuses on technologies researched in European FPs, specifically FP7 and H2020 projects from the TRIMIS database. Within these projects, technologies were identified within technology themes through a Grounded Theory approach (Glaser and Strauss, 1967). An iterative approach led to the development of a consistent taxonomy for transport technologies and technology themes.

Figure 3 provides an overview of the methodology used for the technological assessment of the projects (Gkoumas et al. 2019).

Figure 3. Technology assessment methodological steps.



Source: Gkoumas et al., 2019

1. First, the results of a study that identified technologies within European transport research projects (INTEND, 2017) were analysed by three researchers who have complementary experience in the field of transport innovation and who have individually assessed the technology list. Based on this review, the researchers came up with a standardised approach on what constituted a distinct technology and how to label them.
2. Following this approach, all project descriptions were assessed and flagged when a technology was mentioned or hinted. This filtering exercise was required because EU-funded projects also cover non-technology focused projects. Once a technology was flagged in the project description, another researcher would validate the flagging and record the technology name.

3. In a next step, the full list of technologies was evaluated, and the labelling of similar technologies was aligned. Existing taxonomies, such as those under the Cooperative Patent Classification (CPC, 2019) were used as a basis for the labels.
4. When the technology list was established, a number of overarching technology themes was defined. Themes enable a better understanding of how technologies cluster together and which fields of research receive relatively greater interest. An extensive list of themes was created and consequently reduced to the minimum number of themes under which all technologies could still be logically placed.
5. Moreover, the funds associated with each technology were determined by linking them with the total project budget. If multiple technologies were researched in the project, the budget allocated to the technology of interest was determined by dividing the project budget by the number of associated technologies. The limitations of this attribution approach are acknowledged, but it is considered to be transparent and appropriate in the absence of technology-budget reports.

Finally, a set of metrics was established to assess the identified technologies. These metrics are intended to indicate the potential for the technology to be taken forward to application through the level of support for its development.

For the current assessment, the TRIMIS database with entries as of April 2020 has been used. The technology database includes 868 technologies, under 45 overarching technology themes, researched in 1,797 EU funded projects from FP7 and H2020.

2.2.2 Qualitative assessment methodology

This NETTS report encompasses the identification and analysis of new and emerging transport technologies, based on the technologies that have been (and are being) researched by projects funded under the FP7 and H2020 programmes, including the development phases of those technologies, as allocated in TRIMIS. In addition, some selected projects funded by MS (included in the TRIMIS project database) have been included where their work is also relevant to the analysis. The aim of the NETTs task is to analyse the technologies at different development phases in order to identify those that show promise towards implementation and have the most significant effect on the European transport sector.

The approach adopted for the selection of technologies for analysis was to consider the technologies identified at the four development phases used in TRIMIS. These development phases were built on a similar concept to that of the Technology Readiness Level (TRL) introduced by the National Aeronautics and Space Administration (NASA) (Héder, 2017), but the number of readiness levels (or development phases) was reduced from nine to four, reflecting the uncertainty that would be entailed in attempting to be overly precise with the allocation of a TRL, given the limited information that is usually available for the status of the technologies being researched by a project. The four TRIMIS development phases, and their relationship to the NASA TRL scale, are shown in **Table 1**.

Table 1. Technology readiness levels (TRLs) and TRIMIS development phase allocation.

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

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

Two options were identified for the primary focus of this assessment; technologies at a low development phase (i.e. Research or Validation), to give an early warning of potentially disruptive future technologies, or technologies at a high development phase (i.e. Demonstration/prototyping/pilot production or Implementation), to identify technologies that are likely to have an impact on products and operations in the short to medium term.

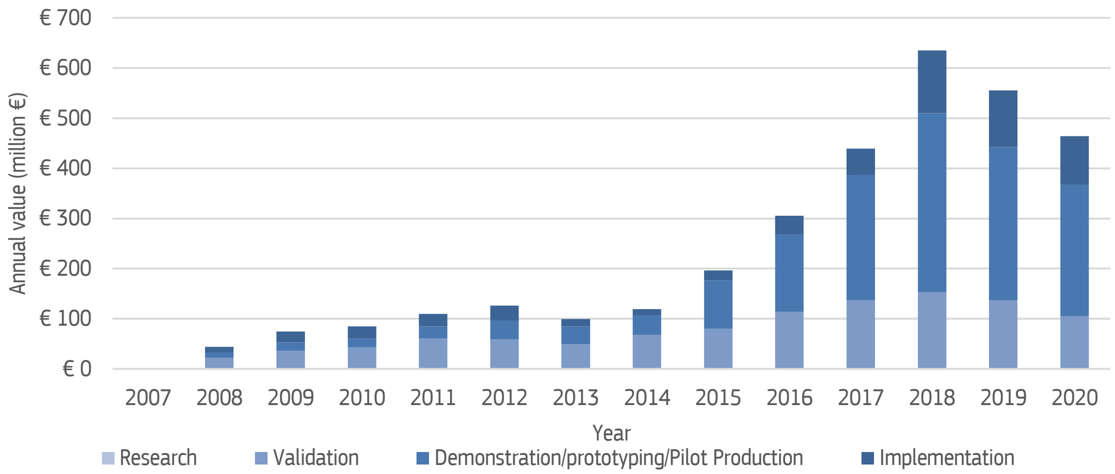
The primary parameter that has been used in the selection of the technologies for review has been the total funding of all projects that have investigated the technology. When identifying the funding value to use for a particular project for a particular technology, the total funding value for the project is divided by the number of technologies that the project has been identified as investigating in order to estimate the 'funding per technology'. In this way, the calculated total funding for the technology should reasonably represent the funding for the individual technology. This parameter gives an indication of the total effort that has been employed to bring the technology to its current status and also indicates the level of interest and expectation there is in the potential of the technology. The nature of the funding schemes for the research under which the technologies have been developed is of key relevance to the use of this parameter. In most cases, the EU funding scheme will only pay 50% of the costs incurred by industry and other large organisations; Thus, a high level of funding for a technology indicates sufficient interest by industry to have invested considerable own resources in its development.

Other parameters that have been used to gauge the level of support and management capability for taking a technology forward towards actual application are the number of organisations that have been involved in projects that have researched the technology and the total number of projects that those organisations have been involved in.

The approach described above was used to identify the technologies at a low development phase that have received high levels of funding and for which the numbers of organisations (and projects) indicate a high level of interest and capability in developing the technologies further. These technologies were then reviewed to understand what they might represent in terms of contributing to the future development of transport systems and a 'Top 20' of promising technologies was selected for in-depth review. The aim of the reviews of these technologies was to present the current status of the technology, how its application might influence future transport systems and what its impact may be (e.g. on GHG emissions). The readiness of the market for the technology and any other changes (e.g. in regulations) or developments that may be needed for the technology to find applications in actual products are also addressed.

Figure 4 provides an overview of the evolution of the annual value of projects by development phase of technologies investigated. Investments peaked in 2018, while the ratio between development phases has remained overall constant.

Figure 4. Annual value of projects by development phase of technologies investigated



Source: TRIMIS

Focusing on technologies in low development phases (research or validation), **Table 2** provides the allocation of projects, the value of technologies, the number of technologies and the number of organisations under STRIA roadmaps. As can be observed, there are many differences among the roadmaps, with VDM being the dominant one on all technology related figures.

Table 2. Allocation under STRIA roadmaps of technologies in low development phases and related figures

Roadmap	Number of projects	Value (mil €)	Number of technologies	Number of organisations
VDM	645	1981	323	2490
INF	243	799	88	727
ELT	230	776	117	870
NTM	218	657	89	656
ALT	134	572	55	540
CAT	168	557	65	481
SMO	159	527	47	325

Source: TRIMIS

2.3 Patent analysis

TRIMIS currently focuses on publicly funded research projects but aims to provide additional insights into private investments and research outputs. For this, patent data provide a solid and well established source of information. Moreover, patent data are highly standardised and can be retrieved from different countries. As such, they enable comparative analyses on how Europe performs versus other regions in terms of transport R&I.

The JRC team working for TRIMIS collaborates with the JRC researchers behind the Strategic Energy Technologies Information System (SETIS) to gather information on transport patents. The SETIS team has extensive experience with patent-based innovation analysis (e.g. Georgakaki et al., 2018) and the collaboration makes that TRIMIS can rely on robust patent data and analyses.

The patent data are linked to existing information on projects, organisations and technologies, with the aim to map technology value chains.

2.4 Scientific research analysis

Publication data provide a rich source of information which shows where academic transport R&I occurs, and what its direction is. The data can provide a complementary perspective compared to project and patent-based analysis.

Bibliometric analyses, based on the Scopus dataset, are used for the analysis of the various STRIA roadmaps. Similar to patent data, publications allow for the comparison of various countries and regions across the globe.

By linking project, patent and publication data, greater insights into transport R&I can be provided from research till implementation.

3 NETT assessment

This section analyses the “Top 20” individual technologies, identified from the set of technologies at a low development phase. The technologies analysed are summarised in **Table 3**; the following sections then focus on the status and potential of each technology.

Table 3. Top 20 technologies selected for in-depth assessment

Technology	Number of projects	Value of projects	Relevant STRIA roadmaps	Relevant transport modes
Smart sensors and smart running gear components for self-diagnosis	4	€98,364,783	INF,VDM	
Ultra-high bypass ratio and pressure ratio aircraft engines[7]	23	€176,319,614	ALT, VDM	
On-board testing systems for ETCS	2	€40,836,473	CAT,NTM	
Mobile CNG Fuelling	1	€58,109,226	ALT, INF	
Hybrid laminar flow control	1	€49,595,633	VDM	
Open platform concept for mobility services	5	€37,633,507	SMO	
Truck platooning	3	€33,089,759	CAT,NTM	
Predictive virtual testing of composite structures up to failure	1	€32,551,672	VDM	
Holistic life cycle performance assessment methods	2	€31,983,742	VDM	
Safety (and maintenance) improvement through automated flight data analysis	6	€30,516,476	NTM,VDM	
Battery management system module	8	€28,714,367	INF,ELT,VDM	
EV component modelling tools	5	€28,119,514	SMO,ELT,VDM	
Electric propulsion system for vessels	3	€28,071,429	INF,ALT,ELT	
Collision avoidance system	6	€25,739,032	CAT,NTM,VDM	
Nanomaterials for structural health monitoring	1	€25,356,214	VDM	
Hydrogen storage system	7	€22,600,042	INF,ALT,ELT, VDM	

[7] This technology encompasses three individual technologies, as assigned to projects in TRIMIS; ‘Lean combustion for ultra-high pressure ratio’, ‘Ultra-high bypass ratio jet engine’, ‘Ultra-high pressure ratio compressors’

Technology	Number of projects	Value of projects	Relevant roadmaps	STRIA	Relevant transport modes
Vehicle energy management systems	7	€21,910,902	CAT,NTM,ELT, VDM		
Computer simulations modelling climatic impact on Arctic marine transportation	2	€21,574,964	NTM,VDM		
Electric ferry	1	€21,303,821	ELT		
Evacuation model validation data-sets	3	€20,869,968	CAT, VDM		

Transport mode icons: Air Rail Road Water Multimodal

Source: TRIMIS

3.1 Technology 1 – Smart sensors and smart running gear components for self-diagnosis

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
4	€98,364,783	Research		INF, VDM

Smart sensors for self-diagnosis are sensors that include an internal circuit capable of showing if the reading is likely to be true or whether there may be a malfunction with the sensor. When incorporated into an aircraft, they can also be used to remotely identify mechanical issues with the aircraft, which can then be transmitted to the mechanics on the ground.

This technology can include a series of sensors embedded into composite structures to calculate the location and force of impacts, critical for testing the strength of modern composite structures before manufacture or for monitoring potential damage to the structure in service. It could also use fully depleted silicon on insulator (FD-SOI) technology for a high performance, low power processor to run the sensor. Applying a voltage near the processor allows control of the speed/power trade-off, for dynamic use of the processor.

Sensors can also be used on the running gear components of trains. These might be embedded self-powered sensors that monitor wheels and axles, or low-cost sensors that can diagnose the health of the gear chain, bearings and motor unit[8]. They can also be used for diagnosing the condition of suspension components.

3.1.1 Development of technology to date and current status

The EXTREME project set out to develop measurement and simulation methods to aid the manufacture of composite aircraft structures, specifically under extreme dynamic loadings. This project finished in 2019 and was able to produce:

- an optical measuring device to test surface strain;
- a concept for smart impact sensing with fibre-optic sensors;
- a concept of tailored embeddable sensor-actuator layers (TEmSAL) for the impact location and force sensors;
- techniques for post-damage characterisation[9].

The EXTREME project was funded by the H2020 programme 'Smart, Green and Integrated Transport'.

[8] http://www.run2rail.eu/Page.aspx?CAT=STANDARD&IdPage=e3da97ae-d084-4e45-bad3-f14e59eb504a
[9] https://www.extreme-h2020.eu/progress/wp6-ndtshm-sensing/

The OCEAN12 project plans to develop a 12nm FD-SOI platform to be used in a range of applications, from autonomous vehicles to smart sensors on aircraft. There are already 28nm FD-SOI processors available and this project will build upon those to reduce their size to 12nm, increasing their power. If successful, a performance boost of 15% over current fin field-effect transistor (finFET) technologies and a power saving of up to 50% can be expected[10].This project started in April 2018 and has since released a website, it is set to run until December 2021 when more results will be available. This project received funding of €96 million with around 75% of this from the market, the remainder was funded by the H2020 programme 'Leadership in enabling and industrial technologies'. The OCEAN12 project has received about 95% of all funding for the development of this technology.

The RUN2Rail ('innovative running gear solutions for new dependable, sustainable, intelligent and comfortable rail vehicles') project has produced a modular, flexible architecture for the on-board condition monitoring system that enables integration of modern technology for sensors, processing units, data storage, communication and power feeding devices[11]. They have calculated how many sensors will be required and where they should be placed for optimal research in case studies. A review of the existing technology that could be useful has been completed. They have started to define the data processing techniques for the extraction of the necessary health information. The funding for this project was provided by the H2020 'Smart, Green and Integrated Transport' programme.

The technologies described above have received over €103 million in funding.

3.1.2 Potential application of technology

These sensors could be fitted to a number of parts around an aircraft including but not limited to:

- thrust reverser actuation systems, including the identification of whether they are stowed or deployed;
- doors and whether they are open or closed as well as locked; cargo loading latch detection;
- evacuation slide door lock mechanism;
- flight controls including flaps, slats and spoilers;
- landing gear position and whether there is any weight on the wheels.

The move from metals to composites in aircraft construction significantly increases the need for structural health monitoring sensors. Damage to metals is easily identified during routine inspections due to visible cracks, whereas damage to composites is often below the surface and not visible. An in-built sensor would enable inspections throughout the life cycle of the structure. The technology used for inspections can also be used in the lab during the design and manufacture process to identify flaws before the component is delivered.

Sensors can be applied to trains across Europe, from freight to passenger. They can also be applied in smaller quantities to test trains, gaining results to increase efficiency and performance that can be subsequently incorporated in commercial trains at the manufacturing stage.

3.1.3 Potential impact of technology

The introduction of smart sensors in aircraft structures could contribute to improving overall flight efficiency, as the pilot will be able to avoid unnecessary delays and diversions given the knowledge that a warning is related to a sensor failure rather than a true equipment malfunction.

Repair times can also be reduced as mechanics can be sent detailed diagnostics before the aircraft lands, allowing them to prepare all the required tools needed to fix the issue. The extra information provided from the smart sensor also reduces long troubleshooting sessions as they can immediately know if it is the sensor at fault or the system target.

Flight safety should also increase as sensor failures have resulted in disastrous consequences in the past. Air France Flight 447 crashed into the South Atlantic after airspeed measurement sensors became obstructed by ice crystals, this led to a series of warning lights causing the pilots to act incorrectly and stall the aircraft[12].

[10] https://www.globalfoundries.com/technology-solutions/cmos/fdx/12fdx
[11] https://cordis.europa.eu/project/id/777564/reporting
[12] https://www.spiegel.de/international/world/death-in-the-atlantic-the-last-four-minutes-of-air-france-flight-447-a-679980.html

With a smart sensor installed, they might have been able to identify the problem rapidly and followed the right course of action.

Direct impacts can be seen by product manufacturers, they could use data gathered from the integrated sensors to produce lighter, smoother, less noisy trains that can also last longer. This can have a significant environmental impact as modern trains become more efficient.

3.1.4 Alignment of technology with EU transport policy

With the decreased downtime of aircraft due to quicker repair times and a reduction in redirected flights due to faulty sensors, air traffic management should be significantly more efficient, contributing to the achievement of the 2011 White Paper goal of a modernised air traffic management infrastructure.

With trains able to carry more and travel faster, the transition from road freight to rail would be made easier, in accordance with the goals of the European Green Deal (European Commission, 2019).

3.1.5 Market drivers and readiness for technology

Sensors are already currently in use on all commercial aircraft so an upgraded version should be relatively easy to adopt. Sensors built into composite structures may take longer to arrive as they have less scope for retrofitting.

Trains already have sensors, so there should be little carrier to incorporating improved versions. The embedded sensors may take longer due to manufacturing and train lifetime issues, with trains generally lasting 30 years.

3.2 Technology 2 – Ultra-high bypass ratio and pressure ratio aircraft engines

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
23	€176,319,614	Validation		ALT, VDM

The bypass ratio (BPR) of an engine is the ratio between the mass flow of air bypassing the engine core (having passed through the fan at the front of the engine) and the mass flow of air passing through the core[13]. An engine that produces significantly more fan thrust than jet thrust is known as a high bypass engine, with an ultra-high bypass ratio engine have a bypass ratio greater than 12. High BPR engines offer reduced engine noise and increased efficiency levels. The overall engine pressure ratio (OPR) is the ratio of the pressure at the exit of the compressor to that at the entry to the engine. High OPR engines also offer increased efficiencies, but they also have increased combustion pressures and temperatures, which can contribute to increased emissions of nitrogen oxides (NO_x). The term 'ultra-high OPR' is applied to concepts for engines with OPR levels of 60 or greater[14].

3.2.1 Development of technology to date and current status

The aims of reducing aircraft noise and fuel consumption (and hence CO_2 emissions) have driven engine development to target increased bypass ratios and pressure ratios for many years. On large (twin-aisle) aircraft, these rose from values of around 5 (BPR) and 25 (OPR) in the 1970s to 7.5 and almost 40 respectively on the engines fitted to the Airbus A380, which entered service in 2007. Subsequent new aircraft types, such as the Boeing 787 and Airbus A350, have used engines with BPR and OPR values of about 9 and 50, respectively. Recently (since 2016), smaller, single-aisle, aircraft types have also adopted engines with high BPR and OPR values, such as the Pratt & Whitney PW1133G, with BPR and OPR values of 11.5 and 38.0. To meet the targets for reduced CO_2 emissions, such as those set in the ACARE Flightpath 2050[15], future aircraft types will need engines with BPR and OPR values approaching, and even exceeding, the 'ultra-high' thresholds.

[13] https://www.britannica.com/technology/jet-engine/Medium-bypass-turbofans-high-bypass-turbofans-and-ultrahigh-bypass-engines#ref135185
[14] https://www.grc.nasa.gov/WWW/k-12/airplane/epr.html
[15] https://www.acare4europe.org/documents/latest-acare-documents/acare-flightpath-2050

At the same time as targeting the increased BPR and OPR for engine efficiency, it has been recognised that improved technology combustors are required to enable engines to meet existing regulations for NO_x emissions[16] and to reduce them further to meet future targets. This has resulted in a focus on 'lean burn' combustor research, which is expected to enable low NO_x emissions even for ultra-high OPR engines.

The ASPIRE project found specific fuel consumption improvements of 15% to 17%, relative to year 2000 levels, based on an increased bypass ratio of 10-12 at a pressure ratio of 40[17], for aircraft types that will enter into service in the mid-2020s. It is now researching the technologies needed to deliver even higher bypass ratios of between 12 and 20. During this project DLR designed a fan/outlet guide vane (OGV) combination with a bypass ratio of 16 to be analysed by Airbus, ONERA and NLR as a basis for aerodynamic computations. This allows for a detailed cross comparison of computational fluid dynamics methods to achieve accurate predictions of the fan on airframe performance and gave detailed understanding of the performance of a fan system designed for such a high bypass ratio. The ASPIRE project was funded under the H2020 programme, with total funding of €3.5 million, the EU contribution to which was €3 million.

The LEMCOTEC project, which was funded under FP7 and ran from 2011 to 2017, also investigated ultra-high pressure ratio engines, considering OPR levels of up to 70. The project developed design concepts for lean burn combustors and constructed and tested three alternative designs for different aircraft design concepts[18]. The test results indicated reductions in NO_x emissions that were greater than targeted, with reductions of up to 77% relative to year 2000 levels being achieved.

As part of the LPA GAM 2018 project (part of Clean Sky 2) a specific objective was to narrow down a selection of key technologies to integrate an ultra-efficient ultra-high bypass ratio (UHBR) turbofan engine into an aircraft, with a large-scale flight demonstration planned. To date, the integration and performance review of the acoustic liner technology (a key technology in reducing UHBR engine noise) into an UHBR engine has been developed to TRL3; with the flight-test demonstration planned, but not yet conducted.

3.2.2 Potential application of technology

This technology is expected to be required to allow future aircraft types to achieve the targeted reductions in noise, CO_2 and NO_x emissions. Although historically new engine technologies have first appeared on large, long-haul aircraft types, recently smaller aircraft types have also adopted high BPR and OPR engines, so the new technology can be expected to appear on such types as well.

3.2.3 Potential impact of technology

Using ultra high bypass ratio engines in aircraft can provide substantial improves in fuel consumption, with estimates showing a reduction in fuel burn of 50%. The development of the lean combustion technology has the potential to give reductions in landing and take-off NO_x emissions of 75%[19].

Another benefit would be the reduction in noise pollution created by aircraft, with noise levels 42dB below the Chapter 4 noise level regulations[6]. These reductions in environmental impacts will be needed if aviation is to meet its overall emissions reduction targets while still accommodating growth levels of 4% to 5% per annum.

3.2.4 Alignment of technology with EU transport policy

The reductions in fuel burn and emissions from aircraft engines through the adoption of ultra-high bypass ratio and pressure ratio engines, coupled with the combustor technology improvements being researched to complement them, will contribute to meeting the EU targets of a 50% reduction in transport emissions by 2050 and improvements in air quality around airports.

The increased fuel efficiency of the aircraft perfectly aligns with the ICAO standards for CO_2 emissions of new aircraft types in 2020 and the ACARE Flightpath goals to reduce CO_2 and NO_x emissions by 75% and 90% respectively.

[16] Emissions regulation for aircraft engines are defined by the International Civil Aviation Organisation (ICAO). The regulations currently in force for new engine types are known as 'CAEP/8'; details can be found at : https://www.easa.europa.eu/sites/default/files/dfu/171123%20Introduction%20to%20the%20ICAO%20EEDB.pdf

[17] https://cordis.europa.eu/project/id/681856/reporting

[18] http://www.lemcotec.eu/page/achievements.php

[19] https://www.hq.nasa.gov/office/aero/pdf/asm_presentations_promise_and_challenges1.pdf

3.2.5 Market drivers and readiness for technology

Alongside policy drivers for reductions in emissions, fuel is a major cost for airlines, so there has long been pressure on aircraft and engine manufacturers to reduce the fuel consumption of their products. Although an individual aircraft may remain in service for a considerable number of years, the growth in demand for air travel leads to continual fleet renewal, so there is a ready market for new technology aircraft with reduced fuel consumption (and hence reduced CO_2 emissions). From a regulatory point of view, there is also considerable pressure on NO_x emissions (the CAEP/8 NO_x regulation, which entered into force in 2014, represented a reduction in allowable emissions of more than 37% relative to the CAEP/2 regulation that was in force in 2000), so lean burn, or similar, combustion technology will be required to allow the future engine types to enter service.

3.3 Technology 3 – On-board testing systems for ETCS

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
2	€40,836,473	Research		CAT, NTM

The European Train Control System (ETCS) is the signalling and control component of the European Rail Traffic Management System (ERTMS). The ERTMS is the system of standards for management and interoperation of signalling for railways in the European Union.

ETCS is a system designed to calculate the safe maximum speed for each train; which happens continuously throughout the journey. The system also includes an on-board unit which can take control of the train if the maximum speed is exceeded. ETCS has the potential to remove the need for trackside signalling by incorporating radio-based data transfer that can monitor the spacing between trains along the railway network. The ETCS is made up of various levels:

- ETCS Level 0: ETCS-compliant trains do not interact with trackside equipment; due to missing ETCS compliance. This level applies when an ETCS-fitted vehicle is used on a non-ETCS route. The on-board system monitors the maximum speed of the train; however, the train driver must observe trackside signals.
- ETCS Level 1: ETCS is installed on trackside and on-board; allowing for transmission of data from track to train (and vice versa) via an electric beacon that lies between the railway lines. The trackside signals communicate with the on-board unit and displays permission for the train to proceed.
- ETCS Level 2: Similar to Level 1, although the electric beacons are only used to detect the exact train position. The continuous data transmission is instead transferred via wireless communications using a global system for mobile communications (GSM). This GSM offers higher data transfer speeds compared to the electric beacon as described in Level 1. Level 2 is a digital radio-based system, which make it possible to operate trains without trackside signalling.
- ETCS Level 3: Level 3 also operates via a digital radio-based system. The advance over Level 2 is that Level 3 offers full radio-based train spacing. By transmitting the positioning signal to a radio block centre, it is always possible to determine if a point along the route is sufficiently clear; hence allowing trains to proceed safely. ETC Level 3 is currently under development.

3.3.1 Development of technology to date and current status

Previous research has already seen developments up to ETCS Level 2, with some short stretches of rail line equipped with, and operating at, ETCS Level 2 in Switzerland, Italy, the Netherlands, Germany, France, Sweden and Belgium.

The projects currently researching this technology are focused on migrating the current ETCS from Level 2 to Level 3. The projects researching on-board testing systems for ETCS have activities including a novel positioning system to migrate ETCS from Level 2 to Level 3; and ensure the evolution and backwards compatibility of ETCS technologies. The project work is conducted by a wide variety of partners, including (but not limited to) technology companies, universities and railway companies.

3.3.2 Potential application of technology

In practice the application of each of the ETCS levels is different. Up to ETCS Level 2 there is a need for trackside equipment, with Level 3 adding in the requirement for a central control system which removes the need for the trackside equipment. Under each ETCS level, the driver / crew will receive constant information on the trains position and speed; and any warning messages will be displayed in order for the driver / crew to react and adjust accordingly. There will probably be a need for some training for crew members to effectively operate with ETCS on board.

The on-board testing systems for ETCS will allow for the development of the different ETCS levels. This is because different ETCS levels require different on-board testing systems; therefore, the development of this technology will enable the benefits of the wider ETCS technology.

3.3.3 Potential impact of technology

The benefits of the ETCS technology include the removal for the need for trackside equipment. Between 2016 and 2017, there were 19,000 signal failure faults that caused delays of more than 100 minutes in the UK alone[20]. By incorporating Level 3 ETCS, and subsequently removing the need for trackside signals, this technology could improve the reliability and safety of the network. As a consequence of improved network reliability and safety, ETCS will allow for enhanced network capacity and speed; allowing for a higher operational performance.

Another key benefit of implementing ETCS technology is the potential for an interoperable European railway network. If standards were in place across Member States, then the safety and reliability benefits could be achieved throughout the trans-European railway network.

As with other areas of increased digitalisation, there is a need for cyber security to be in place for this technology to be effective and secure.

3.3.4 Alignment of technology with EU transport policy

Due to the higher operational performance, ETCS will contribute to the European Green Deal policy of freight modal shift from road to rail. This is because freight often suffers as a result of limited network capacity; therefore, capacity improvements will see benefits for the rail freight sector.

The White Paper of 2011 sets targets of completing a European high-speed rail network by 2050. The implementation of ETCS will improve safety; and hence allow higher speed trains to operate across the network.

3.3.5 Market drivers and readiness for technology

ETCS technology can see an improvement in network capacity and speed, which would see an improvement in railway operators' performance. As a result, there is a market demand for this technology from a private operator's point of view as they would be able to run more trains across the network and hence see an increased revenue.

ETCS Level 3 operates from a global system for mobile communications, which could see data transferred via 4G or 5G services in the future. This could raise the interest of mobile network operators, as the use of 5G networks would be required for ultra-fast data transfer.

3.4 Technology 4 – Mobile CNG fuelling station

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
1	€58,109,226	Research		ALT, INF

A compressed natural gas (CNG) fuelling station is a system to refuel vehicles that run on CNG. CNG has lower CO_2 emissions than conventional fuels (petrol or diesel); and can also be partially replaced with certain

[20] https://www.telegraph.co.uk/news/2018/08/04/signal-failure-delays-could-become-complaint-past-train-company/

biofuels (e.g. biomethane) up to a blend limit. Refuelling CNG vehicles takes a similar time as conventional refuelling (a few minutes). The refuelling station can be placed along existing gas pipelines, subject to constraints due to varying pressures. The alternative CNG delivery option is to have a 'mother station'; which is a large station often located near a natural gas supply and delivered to the smaller stations via mobile tube trailers to create a virtual pipeline.

The project researching this technology covers a variety of aspects relating to CNG refuelling. Within this project there is a focus on mobile refuelling stations, which are able to be moved along the road network to key locations where the gas pipelines cannot reach. This allows for a greater network of CNG refuelling stations in desired locations. Whilst CNG refuelling stations are not a new technology, it can be said that mobile CNG refuelling stations are currently at a low development phase.

All of the total project value for this technology is associated with from the project 'Green Connect - A public CNG network' financed through the Connecting Europe Facility (CEF) Transport programme. In most cases, CEF projects aim to demonstrate and roll-out technologies that are already well advanced; however, in this case (as noted above) the project also includes the further development of less advanced technology to potentially meet demand that cannot be met using more conventional CNG refuelling stations.

Nevertheless, recent research suggests CNG engines might have higher particle number (PN) emissions than diesel engines; which remains a crucial issue to be addressed if gaseous fuels are introduced as a viable alternative to diesel (Ortega Hortelano et al. 2019).

3.4.1 Development of technology to date and current status

As of January 2020, there are currently 3,737 CNG refuelling stations in Europe[21]; CNG fuelled vehicles are not a new technology. However, the projects researching CNG fuelling stations are currently focused on developing stations that can run on 'renewable' CNG (i.e. biomethane) and mobile fuelling stations. Mobile fuelling stations are designed to be distributed into key locations where natural gas pipelines cannot reach. This allows the CNG network to be extended and give additional coverage.

The projects researching this technology are aiming to raise the technology readiness level and deploy mobile and renewable CNG stations in the real world.

3.4.2 Potential application of technology

In practice this technology will be operated in a very similar way to conventional internal combustion engine (ICE) refuelling. The mobile refuelling stations will allow for vehicle refuelling in key locations that will offer drivers additional benefits in terms of being able to refuel along main network corridors.

3.4.3 Potential impact of technology

CNG-fuelled vehicles have a lower carbon output at the tailpipe than petrol, and similar to diesel[22]. However, to gain the full benefits of using CNG as a fuel, from the extraction to the powering of vehicles, research will need to be conducted into production methods that include carbon-neutral natural gas (or methane). Although the use of CNG achieves only a limited level of decarbonisation, biomass digestion and power-to-gas technology to produce biomethane (or synthetic methane) have the potential to reduce CO_2 emissions.

Another benefit of the technology is that there is potential to blend renewable biofuels, such as biomethane, with the CNG to reduce CO_2 emissions further. The mobile refuelling stations will also allow for CNG to be deployed away from the existing pipelines; extending the CNG network and subsequently increasing the attractiveness of a CNG vehicle.

3.4.4 Alignment of technology with EU transport policy

This technology will help towards the ramp up and deployment of sustainable alternative transport fuels, thus contributing towards meeting the goal included in the European Green Deal. Having greater numbers of CNG fuelling stations will increase the attractiveness of CNG fuelled vehicles.

[21] https://www.ngva.eu/stations-map/

[22] https://www.fleeteurope.com/en/new-energies/europe/features/10-reasons-why-cng-new-diesel?a=DQU04&t%5B0%5D=Diesel&t%5B1%5D=CNG&t%5B2%5D=&t%5B3%5D=&t%5B4%5D=LEZ&curl=1

The alternative fuels infrastructure directive[23], introduced in 2014, places a requirement on Member States to develop national policy frameworks for the market development of alternative fuels and their infrastructure. Specific requirements include the availability of an appropriate number of CNG refuelling points in urban/suburban and other densely populated areas by 2020 and along the Trans-European Transport Network (TEN-T) core network by 2025. The introduction of mobile CNG refuelling points will help to achieve greater CNG distribution along the TEN-T core network by allowing the placement of CNG refuelling points at strategic locations where there is not a major gas pipeline in close proximity.

From a policy point of view, CNG offers possible short – and medium-term solutions if the associated emission and leakage issues are overcome, however the electrification of transport might be a more beneficial and attractive solution to long-term decarbonisation.

3.4.5 Market drivers and readiness for technology

The overall CNG vehicle market was worth $109,784 million in 2017, with a projected market value of $185,000 million by 2025 globally. Vehicle original equipment manufacturers (OEMs) and infrastructure providers will help to drive the CNG market. Natural gas suppliers will also have a keen interest in this technology.

The main barrier to the widespread uptake of this technology comes from other non-conventionally fuelled vehicles, such as battery electric vehicles (BEV) and hydrogen fuel cell electric vehicles (FCEV). These other non-conventionally fuelled vehicles can offer a lower carbon output per km, with even lower output when the electricity is from low-carbon sources. CNG fuelled vehicles will never reach full decarbonisation, which the other alternatively fuelled vehicles can (with appropriately-sourced electricity). CNG fuelled vehicles can offer a stepping stone to full decarbonisation through renewable biogas (such as biomethane); however, the decarbonisation potential of renewable biogas will depend on how the biogas is produced.

3.5 Technology 5 – Hybrid laminar flow control

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
1	€49,595,633	Validation		VDM

In fluid dynamics, the boundary layer is the region of fluid close to a solid surface, over which the fluid (e.g. air in the case of an aircraft) is flowing, in which the velocity of the fluid has been reduced by a combination of friction (between the molecules of the fluid next to the surface and the surface itself) and viscosity (which causes forces between fluid molecules to extend the effects of the friction further from the solid surface). Within the boundary layer, the flow may be laminar or turbulent; laminar flow is characterised by smooth or regular paths of particles of the fluid, which is in contrast to turbulent flow, which is characterised by the irregular movement of particles of the fluid. In laminar flow, the fluid flows in parallel layers, with no disruption between the layers[24]. In general, boundary layers are initially thin (e.g. near the nose of the aircraft or the leading edge of the wing) and laminar. As the fluid flows over the surface, the thick ness of the boundary layer grows and, at a point that depends on a variety of factors, it undergoes a transition to turbulent flow. Turbulent flow over aircraft wings can cause additional drag on the aircraft, which increases fuel consumption. Laminar flow over the aircraft structure is ideal, as it allows the aircraft to fly with minimal drag.

Hybrid laminar flow control (HLFC) is an active way to reduce drag on an aircraft in flight by reducing the regions of turbulent flow and increasing those of laminar flow. This improves aircraft efficiency and reduces fuel consumption. Suction techniques are usually applied over a proportion of the aircraft's wing, which allows for a delay in transition of the boundary layer from laminar to turbulent flow. By reducing turbulent flow around the aircraft wings, the aircraft can fly with reduced drag and increased stability. This technology is not only applicable to aircraft wings, but any part of the aircraft structure that be impacted by turbulent flow. The challenge is that laminar flow is difficult to maintain over the entire surface of a wing or tail; the variations in

[23] https://ec.europa.eu/transport/themes/urban/cpt_en
[24] https://www.reactor-physics.com/engineering/fluid-dynamics/laminar-flow-vs-turbulent-flow/#:~:text=In%20fluid%20dynamics%2C%20laminar%20flow,no%20disruption%20between%20the%20layers.

flow velocity across the wing, together with small imperfections in the surface, will trigger a transition to turbulent flow, increasing drag[25].

3.5.1 Development of technology to date and current status

The large passenger aircraft grant agreement for members (LPA GAM) project has run test flights on aircraft fitted with natural laminar flow technology and assessed options for hybrid laminar flow control system using suction panels to direct airflow. Additional areas of research performed by the project included boundary layer ingestion (in which the fuselage boundary layer is ingested into the engines, improving their efficiency) and a demonstration hybrid electric propulsion generator. This project had a total funding of €248 million, of which €185 million was provided through the EU H2020 programme. The assessment of this project for TRIMIS identified five technologies being researched, therefore the value of the project for this technology for this project is just under €50 million.

Within the LPA GAM project (part of the Clean Sky 2 programme) there are notable state-of-the-art targets identified for HLFC technology. Demo 1 will focus on the development of HLFC for the horizontal stabiliser (tailplane) and large-scale ground based testing to achieve a fully functional HLFC on a leading edge segment at TRL6. Demo 2 will include the design, build and test of a large-scale ground based demonstrator of HLFC technology applied on a wing at TRL4. A flight test demonstration to acquire data in specific flight conditions and representative of airline operations will be carried out using an Airbus A320 aircraft fitted with a HLFC test fin developed in a former EU project[26]. The key results of this project are expected to be HLFC demonstrations on the tail and wings of aircraft, the manufacture and large-scale ground test of a segment of HLFC leading edge; the fulfilment of the aerodynamic, industrial and operability requirements of the technologies, and a simplified HLFC concept for high production rates at acceptable cost. At the completion of this project it is expected that the technology will have raised from validation to demonstration development phase.

3.5.2 Potential application of technology

This technology could be applied to any size of aircraft, and all key aircraft structures such as the wings and tail. Turbulent airflow is reduced by applying suction through small holes in the aircraft structure, which effectively pulls the turbulent layer through the holes and creates a laminar flow layer in its place. Once properly tested and standardised, the technology should be able to be applied to all future aircraft structures.

3.5.3 Potential impact of technology

The main benefits of HLFC come from reduced drag on the aircraft structure in flight and therefore reduced fuel consumption. Controlling the turbulent flow layer around the structure can reduce fuel consumption and reduce carbon emissions by up to 10%[27].

As this technology can be applied to many types of aircraft, the benefits seen from this technology can be applied to the aviation sector as a whole; hence resulting in a large benefit due to the potential coverage of the technology.

3.5.4 Alignment of technology with EU transport policy

The increased efficiency from reduction in drag results in direct emissions savings from reduced fuel consumption. This alone will not be sufficient to meet the European Green Deal's aim of 90% reduction in transport emissions by 2050 goal (European Commission, 2019). However, there may also be a secondary benefit from reduced fuel consumption; as requiring less fuel results in less energy required, which may pave the way for more sustainable but less energy dense alternative fuels. Using these low-carbon alternative fuels (such as renewable biofuels) can help to achieve the transport decarbonisation targets.

The International Civil Aviation Organisation (ICAO) has adopted standards for CO_2 emissions from aircraft, based on fuel consumption and capacity, which will apply to all newly certified aircraft types from 2020 and all newly manufactured aircraft from 2028[28]. The increased fuel efficiency of HLFC aircraft is consistent with

[25] https://www.wired.co.uk/article/manipulating-airflow-on-777
[26] https://www.cleansky.eu/go-with-the-flow-clean-skys-hybrid-laminar-flow-control-demo
[27] https://www.cleansky.eu/go-with-the-flow-clean-skys-hybrid-laminar-flow-control-demo
[28] https://www.icao.int/newsroom/pages/icao-council-adopts-new-co2-emissions-standard-for-aircraft.aspx

the aims of being able to meet the continued growth in demand for air travel while reducing the environmental impacts.

3.5.5 Market drivers and readiness for technology

There is a large interest within the aviation industry on hybrid laminar flow control; with flight testing of a primitive form of the technology performed by Boeing aboard one of its 787 test aircraft in 2011[29] to achieve a 1% reduction in drag, and the concept of laminar flow control has been investigated by NASA previously in 1995[30]. The previous research by Boeing and NASA were focused on partial laminarisation or aircraft components, and the key difference with the current HLFC systems being researched is the laminarisation of entire wings and structures of the aircraft to achieve much higher reductions in drag. The extent of the technology investigated in LPA GAM can reduce fuel consumption by up to 10%; whereas the previous partial laminarisation by Boeing only reduces drag by 1%.

The obvious immediate market driver for this technology is fuel savings, and therefore savings in fuel cost. In 2018, the amount of aviation fuel consumed (kerosene) within the EU was 62.8 million tonnes[31]. Simple estimates of applying the 10% fuel savings identified by the LPA GAM project discussed above would result in around 6 million tonnes of kerosene saved per year, helping to reduce fuel costs and carbon emissions.

3.6 Technology 6 – Open platform concept for mobility services

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
5	€37,633,507	Validation		SMO

This technology relates to an integrated open data mobility platform, which gathers information from all transport modes and provides information to the user. The platform can include multimodal travel options and will provide a consolidated database of mobility services in real time. This will allow the user to enter a desired origin and destination; with a range of real-time journey options provided.

This technology can also provide information about a wide range of issues, including public bicycles, parking, car sharing, traffic congestion, air pollution levels and alternative travel modes; it is generally associated with the delivery of sustainable urban mobility plans (SUMPs). The end-user is able to make informed decisions on their journeys based on factors such as travel time, cost and environmental footprint.

The technology falls under the wider theme of mobility-as-a-service (MaaS), which aims to shift away from personally owned modes of transport and towards mobility provided as a service.

3.6.1 Development of technology to date and current status

The open platform concept for mobility services can cover a variety of applications. Projects researching this technology have focused on developing models and algorithms for planning journeys in real-time; and incorporating user preferences and traffic data obtained from public sources into a smartphone application. Also investigated within the projects is the development of an open, standardised, data-driven user-centric platform for mobility. This platform aims to allow for collaboration between transport modes and cities and the testing of 'Internet of Everything' (IoE) services.

Partners for projects focusing on this technology are largely public sector, with public transport operators and city councils the main players. This technology is largely at the research and proof-of-concept stage, with the highest project aiming to achieve TRL 5.

[29] https://www.flightglobal.com/boeing-tests-hybrid-laminar-flow-control-for-787-9/100554.article
[30] https://crgis.ndc.nasa.gov/historic/Hybrid_Laminar_Flow_Control_(HLFC)
[31] http://news.bio-based.eu/can-the-european-unions-kerosene-demand-be-met-by-the-amount-of-biomass-produced-in-the-eu/#:~:text=In%202018%2C%20the%20consumption%20of,to%202%2C895%20million%20GJ2.

3.6.2 Potential application of technology

This technology will reach the end-user via a smartphone application. As smartphone uptake was around 62% in Western Europe and 44% in Central and Eastern Europe in 2017[32], this technology could deliver significant benefits quickly. Data will be transferred real-time to the end-user and they will be able to make informed decisions about their travel.

3.6.3 Potential impact of technology

The main aim of this technology is to make travelling using a range of modes easier by facilitating the use of the mode, or modes, that are most appropriate for a particular journey. This in turn will bring the benefits from increased public transport use and decreased personal-car use. This can include benefits such as reduced road congestion, improved air quality and reduced CO_2 emissions. End-users can also be informed of the cheapest travel option, hence saving money for the user.

If active travel is encouraged through the mobility platform (e.g. public bicycles), then public health benefits could also be seen through increased exercise. Additional public health benefits could include the reduction in harmful air pollutants (NO_x and PM).

3.6.4 Alignment of technology with EU transport policy

The open platform concept for mobility services technology will help towards the policy goal to establish the framework for a European multimodal transport information, management and payment system. By reducing road congestion and increasing public transport share or increasing active travel, this technology will also help to move closer to zero fatalities in road transport by 2050.

This technology will help achieve the European Green Deal objective of developing smart systems for MaaS and help to achieve multimodality. The technology has the ability to support SUMPs, which are in-line with EU policy on improving air quality, reducing congestion and reducing CO_2 emissions from transport. The Low Emissions Mobility Strategy {COM(2016) 501} also underlines the important role of shared mobility schemes, such as bike, car-sharing and car-pooling, to reduce congestion and pollution as part of a sustainable urban mobility planning.

3.6.5 Market drivers and readiness for technology

If the technology is considered to be under the wider MaaS theme, then there is a considerable market demand for this technology. The global market size for MaaS in 2018 was $42.3 billion, with a predicted market size by 2026 of $372.1 billion[33]. Whilst the technology open platform concept for mobility services will not be the only technology within the wider MaaS bracket, it could see a similar market growth.

Due to the reliance on ‘big data’ for this technology to really see benefits, the need for a widespread roll-out of 5G could be a barrier to the market deployment of the technology; although it is expected that a 5G network will be developed in the future. There will also be a need to develop relevant policies to ensure the safety and security of the data being used. Standards will need to be defined and their application made mandatory. However, this may not always be the case given that the majority of the data is public sector, and so the mandatory element may not be as relevant in order to implement the open platform concept in cities.

This technology will also be impacted by the overall smartphone uptake in Europe. By 2021, it is predicted that around 522 million Europeans will own a smartphone[32], representing around 70% of the total population. There is a potential risk that this technology will not be accessible for everyone; with the remaining 30% of non-smartphone users not able to benefit from this technology.

[32] https://www.emarketer.com/Report/Internet-Mobile-Users-Europe-eMarketers-Country-by-Country-Forecast-20172021/2002177

[33] https://www.globenewswire.com/news-release/2019/04/01/1790931/0/en/Mobility-as-a-Service-MaaS-Market-To-Reach-USD-372-1-Billion-By-2026.html

3.7 Technology 7 – Truck platooning

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
3	€33,089,759	Validation		CAT, NTM

Truck platooning is an area of research that falls under cooperative, connected and automated transport, specifically regarding heavy goods vehicles (HGVs) along motorways. A platoon is a group of vehicles (HGVs in this case) that follow closely behind one another. The vehicle at the front of the platoon controls the speed, acceleration and braking; the other vehicles in the platoon are wirelessly connected to the lead vehicle and automatically copy its driving behaviours.

The connectivity technology allows for the HGVs to automatically maintain a close distance to each other by eliminating the distance needed to allow for human reaction times. Truck platooning is not driverless technology; all HGVs in a platoon will have a driver at all times to take over manual control or to leave / join the platoon when necessary.

Around 80% of the total funding for this technology is for the project 'ENabling SafE Multi-Brand pLatooning for Europe' (ENSEMBLE) funded by H2020-EU.3.4.

3.7.1 Development of technology to date and current status

There have been developments in general truck platooning, with trials undertaken throughout Europe[34,35]. The trials and pilot tests conducted to date have all focused on the same brand of vehicle, with the same on-board equipment installed. The current research projects are focusing on the development of technology that allows for multi-brand truck platooning. Within the recent projects there is a target to raise this technology from validation to demonstration in the form of a pilot programme.

Multi-brand tuck platooning will, in theory, allow for any HGV to join and leave a platoon irrespective of the vehicle manufacturer. This will allow for an inclusive platooning system and enable the uptake of HGV platooning across Europe. The technology will require the development of regulations and standards to ensure that all vehicle brands can join and leave platoons as necessary.

3.7.2 Potential application of technology

In practice this technology will be implemented via on-board units in vehicles, which will allow for wireless communication between the vehicles. Drivers will, in theory, be able to join a highway and locate the nearest 'truck platoon'. Once in close proximity with the platoon, the driver will be able to 'join' the platoon and the vehicle will be under the lead vehicle's guidance. The driver will be able to leave the platoon when desired.

Any driver may be required to become the 'lead vehicle' and take control of the platoon when at the front. Hence, this technology will probably require additional driver training to ensure that the optimal benefits are achieved.

3.7.3 Potential impact of technology

This technology allows for HGVs to drive closer to each other. This is because the automatic brakes can react much quicker than a human is able to react, which increases road safety by reducing the chances of a potential collision. By reducing the space between the vehicles there is also more available capacity on the roads.

Another benefit of the closer proximity is that the vehicles behind the lead vehicle do not experience as much drag as if they were unconnected to the platoon. The lead vehicle reduces the air resistance that the trailing vehicles have to overcome. This results in less fuel consumption, which has benefits including lower CO_2 and pollutant emissions, as well as reduced operating costs.

[34] http://www.eurekamagazine.co.uk/design-engineering-news/uk-8-1-million-hgv-platooning-project-begins/217770/
[35] https://www.truckinginfo.com/331644/platooning-pilot-in-germany-deemed-runaway-success

3.7.4 Alignment of technology with EU transport policy

Truck platooning technology can help to reduce traffic collisions and improve overall highway safety. It also aligns with the EU policy to develop smart systems for traffic management, which will improve transport cooperativity and connectivity.

This technology also aligns with the European Green Deal objective to develop automated mobility and smart traffic management systems to make transport more efficient and cleaner. This technology is fully aligned with the Europe on the Move policy[36], which aims to have automated driving on motorways (in particular truck platooning) within the 2020s, moving towards full autonomous mobility in the 2030s.

3.7.5 Market drivers and readiness for technology

The global truck platooning market was valued at around $500 million in 2017 and is projected to reach around $4,590 million in 2025[37]. The market is driven by goods and logistics companies with a desire to improve overall efficiency and safety of their operations. Vehicle manufacturers have been project partners within the research projects.

There are some barriers to the implementation of this technology. For multi-brand truck platooning to become commonplace within Europe, all HGV manufacturers must adhere to the regulations and standards developed in order for full connectivity to be achieved. The standards for multi-brand platooning have not yet been developed; one project (ENSEMBLE, end date 2021) has an objective to develop such standards using working groups formed of stakeholders. The drivers would be required to undertake special training; drivers may become less attentive and subsequently slower to react in case of software failure.

Another potential barrier is the on-going debate on which communication technology to use for dedicated short-range communications (DSCR) (Wi-Fi) or cellular (5G)). For multi-brand platooning, all vehicles would need to be equipped with the same communication technology; until there is a clear 'winner' in the Wi-Fi/5G debate, it is unclear which technology truck platooning would use.

3.8 Technology 8 – Predictive virtual testing of composite structures up to failure

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
1	€32,551,672	Research		VDM

This technology uses simulation-based design to provide a quicker and cheaper route to the production of composite aircraft structures, such as the fuselage. Composite structures are objects made from multiple materials that often have significantly different properties, which when combined take on the features of all the initial materials. This can lead to much stronger and lighter final structures, requiring less material whilst providing the same performance. It also allows for large, single one-shot parts to be produced that would previously have taken multiple smaller parts. The current process of production uses physical tests on models, these can be extremely time consuming to build and would be considerably more expensive than running a simulation.

3.8.1 Development of technology to date and current status

The more affordable aircraft through extended, integrated and mature numerical sizing (MAAXIMUS) project examined various areas for improvement in the current state of the technology. They looked at single one-shot assembly that produces large single structures that were previously built by linking smaller multiple structures. They also investigated the required adaption of the assembly line to adjust for the lack of ductility and stiffness of composite structures, as well as improving the confidence levels of simulations to create shorter cycle times. They predict that with these improvements development time and cost will reduce by 20% and 10% respectively. This technology should reduce assembly time by half and bring down production

[36] https://ec.europa.eu/transport/sites/transport/files/3rd-mobility-pack/3rd-mobility-pack-factsheets-automatedconnected.pdf
[37] https://www.alliedmarketresearch.com/truck-platooning-market

costs and weight by 10%[38]. To date the project has improved acoustic models, composite data models and non-destructive investigation data. It has also completed a cost model, based on a generic fuselage. Design of the structural sub-components for the physical tests, used to check the accuracy of the simulation, have almost finished. The manufacturing test coupons have been used to compare experimental and calculated results, with all the non-destructive investigation (NDI) data available.

One of the biggest components of the MAAXIMUS project looked at simulating composite material behaviours during damage initiation, propagation and final failure. The team have carried out comprehensive work on the development of models concerning damage from the micro to the macro scale, making sure to couple effectively between the two and carefully control any errors. The ability to minimise errors is crucial to achieving the confidence required to translate the simulations into real world weight, cost and time savings. A software tool has been developed to transfer the NDI data to the existing simulation tool ABAQUS. The objectives of MAAXIMUS have been widely achieved, utilising the funding of €65 million with €40 million coming from the FP7 Transport programme.

3.8.2 Potential application of technology

The whole aircraft industry could benefit from this technology as it is applicable to composite aircraft structures that are now in widespread use. It can be used on all sizes of aircraft, including civil and military. It is not only beneficial for the aircraft industry, as many other industries could use composite structures, from freight trains to e-scooters. These other industries could adjust the models for structures they need, which would save considerable time compared to creating the models from scratch.

3.8.3 Potential impact of technology

If successful this technology will result in significant reductions in time, as much as 50% in the assembly time of the fuselage. It can also help reduce recurring manufacturing and assembly costs by 10% and reduce the weight of the aircraft by 10%.

It also allows a faster development process, a potential 20% reduction in time from preliminary design up to full-scale test. The development process costs could also fall by 10% due to the higher confidence in the simulations in the numerical optimisation process.

With high confidence levels in simulations right-first-time structure development costs could fall by as much as 5%, this would require new certification that relies on virtual testing. The virtual testing will also help to avoid late and costly changes from unexpected test results.

Being able to test many models makes it possible to create larger single components compared to assembling multiple small components, this results in weight savings that could be as high as 20%. A lighter aircraft will consume less fuel, continuing to save money past the assembly stage.

Not only do all these benefits reduce the cost and time of production, they will lead to reductions in emissions from the industry. Creating models for testing is not only expensive but uses polluting resources that will now be unnecessary. The lighter, more fuel-efficient aircraft will help to reduce CO_2 and NO_x emissions.

3.8.4 Alignment of technology with EU transport policy

An increase in aircraft fuel efficiency from the lighter weight will help to achieve the 90% reduction in transport emissions by 2050 set out by the European Green Deal, along with the goal of improving air quality near airports.

The ACARE Flightpath 2050 has goals of reducing CO_2 emissions by 75% and NO_x emissions by 90% by 2050, with lighter aircraft resulting in more fuel efficient aircraft, this technology could contribute to the achievement of these targets.

3.8.5 Market drivers and readiness for technology

Computational fluid dynamic simulations are already widely used in the aircraft industry, so extending the use of computational simulations to include virtual testing of composite structures should be relatively easy. The

[38] https://cordis.europa.eu/article/id/86619-faster-and-cheaper-fuselage-development

challenge will be to increase confidence in the methods and reduce errors sufficiently to be able to rely solely on simulations to maximise cost reductions and remove the need for physical model testing.

The University of Southampton has recently been awarded a grant of £6.9 million to invest in simulations of composite aircraft structures[39].

3.9 Technology 9 – Holistic life cycle performance assessment methods

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
2	€31,983,742	Research		VDM

The holistic life cycle assessment (LCA) of vehicles would involve looking at the emissions during each section of a vehicle's life, from the mining of raw materials used to build the vehicle up until the eventual breakdown of the vehicle and what happens to those products, whether they are recycled, discarded or reused. The result of the sum of these emissions would provide the life cycle assessment. Emissions may not just refer to CO_2 emissions, for example they could involve the assessment of labour used in mining areas.

An easy to use and transparent software tool would allow for comparisons of different innovations at an early phase in their design. This tool should combine environmental, safety and societal aspects of the whole chain in the vehicle building process. This tool needs to have the capability to compare a number of varying vehicles and adapt to the changes in future economic and environmental climates.

3.9.1 Development of technology to date and current status

The BESST (breakthrough in European ship and shipbuilding technologies) project concentrated on the shipping industry. They have established a unified set of key performance indicators with regards to the LCA, as well as a framework for the LCA at a ship level that covers, costs, environmental performance, safety and future policy and societal requirements[40]. They used more detailed performance indicators and algorithms to assess the life cycle on a system level and link this to the holistic level. This tool can now be used to support decision making, with its modular structure helping to evaluate the difference between technical solutions and absolute values for LCA.

This tool has been tested on three virtual ships, a large cruise ship, a medium cruise ship and a ferry ship. Future scenarios on environment, society, safety and costs for externalities, such as long-term regulation changes, have been produced and then combined with the tool to determine the LCA of the virtual ships. This project received funding from the FP7 Transport programme of €17.5 million with a further €11 million from the market.

3.9.2 Potential application of technology

This technology can be implemented in several different ways. Research to date has focused on application to ships, but holistic LCA can be applied to almost any industry. With current goals to drastically reduce emissions every technological sector could look at its emissions across its whole lifetime, rather than just the running emissions.

The ship software tool, although designed around passenger ships and ferries could be applied to other ships such as small, privately owned boats. It can also apply to ships across the globe and even to individual ship parts that might need replacing.

3.9.3 Potential impact of technology

Using the tool produced in the BESST project allows users to investigate the outcomes of multiple innovations with quantitative results, leading to rational decision making. This will allow the shipping industry to achieve the expected benefits of an overall life cycle cost reduction of €120 million per Panamax ship – a ship capable of carrying 5,000 shipping crates and still able to travel through the Panama Canal[41]. They should

[39] https://www.aero-mag.com/university-funded-to-investigate-lightweight-composite-aircraft-structures/
[40] http://www.besst.it/BESST/horisontal_action.xhtml
[41] https://cordis.europa.eu/project/id/233980

also see reductions in CO_2 emissions of 12% per ship, per year. This project worked in Europe with 20 research institutes, 5 classification societies and 31 ship equipment suppliers; with the EU holding a global market share of 96% for cruise ships and 31% for ferries the tool can be immediately applied to a large proportion of the current fleet resulting in massive benefits.

3.9.4 Alignment of technology with EU transport policy

The 2011 White Paper goal of reducing EU CO_2 emissions from maritime bunker fuels by 40% will be made easier to achieve with modern ships being built to have a lower life cycle cost, a large portion of which comes from the bunker fuels used to power them.

This technology can also help with the European Green Deal aims to reduce pollution in EU ports and the 90% reduction in transport emissions by 2050; as ships can more easily be produced to reduce their CO_2 emissions.

3.9.5 Market drivers and readiness for technology

The shipping industry is one of the slowest to adopt modern, more environmentally friendly approaches to business. This technology makes it far easier for ship builders and owners to appreciate the impact of their vessels, whilst providing them options to reduce the impacts they may have. With this level of accessibility, uptake in new ships could be high, although the relatively long ship lifetime of around 30 years will reduce the rate of penetration in the fleet.

3.10 Technology 10 – Safety (and maintenance) improvement through automated flight data analysis

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
6	€30,516,476	Research		NTM, VDM

This technology is targeted at enhancing flight operational safety and smart maintenance using intelligent and automated flight data monitoring.

A standardised, automated flight data management system, capable of processing large quantities of data, could be used by operators to improve the analysis of all available flight data. This can be made easier using a common methodology of flight data analysis, based on singular points of automation. Analyses from different aircraft types and operators would then be comparable and easily combined.

Self-learning methods could then be used to detect, identify and correct any safety concerns before an incident occurs. This could be built upon current assessment techniques using flight data recorders, providing insight for predictive maintenance cycles.

More specifically, this could involve creating a graphical user interface, based on three-dimensional (3D) icing engineering tools that use numerical simulations, to inform the user of equipment reactions to snow and ice[42]. Current methods rely on empirical data that bring large uncertainties, this results in inefficient systems and a lack of scope for different aircraft designs.

It could also involve using machine learning methods, rather than software programming, to convert speech to text, allowing information to be directly relayed to air traffic management and saving the air traffic control operator from typing out the information[43]. Manual input is often necessary because of language differences such as regional accents and colloquial phrasing; machine learning could use data and automatically learn local variabilities.

3.10.1 Development of technology to date and current status

The SVETLANA (safety and maintenance improvement through automated flight data analysis) project was a joint effort from EU and Russian researchers to develop a common approach to flight data analysis. SVETLANA has developed a new analysis process; initially using data-mining techniques in an automated

[42] https://cordis.europa.eu/project/id/824310
[43] https://cordis.europa.eu/article/id/239630-speech-recognition-technology-for-air-traffic-controllers

detection process. Smart maintenance and flight safety improvements were assessed to develop data-mining algorithms, two patent applications have been filed for these.

Limitations on SVETLANA's system were addressed, making the standardisation of a common analysis process a reality; the compilation of multiple external data sources was made possible as well as improving data filtering techniques. The developers ultimately used aircraft-independent flight data analysis and developed patented anomaly detection algorithms and dedicated human-machine interface support for end-users.

An overall assessment of the analysis system that used both simulated and real flight data, the SVETLANA project was part funded by the FP7 Transport programme and had a total budget of €4 million.

The ICE GENESIS project is investigating the creation of the next generation of 3D simulation models for icing, to improve safety, efficiency and reduce costs for future aircraft. It is concentrating on atmospheric icing conditions, airframe ice accretion, supercooled large droplet icing (diameter above 40 μm) and snow conditions[44]. The project is still ongoing, but the main objectives are to improve existing 3D numerical tools for ice accretion predictions, upgrade and calibrate icing wind tunnels and build a large-scale experimental database of 3D configurations to be used as a reliable reference for the future. The icing wind tunnels will allow the production of snowy conditions with supercooled large droplets and freezing drizzle. The overall budget for this project is around €22 million with just over half coming from the EU H2020 programme.

The MALORCA (machine learning of speech recognition models for controller assistance) project aimed to address the limiting factor for automated air traffic management, the reliance on spoken language for communication. The project analysed 18 hours of non-transcribed and 4 hours of transcribed data from Prague and Vienna, achieving recognition rates of 89% and 61% respectively. At the end of the project recognition rates had risen to 92% and 82% respectively. This project was funded in part by the H2020 programme.

3.10.2 Potential application of technology

In principle, this technology could be implemented immediately as the only requirement is access to sufficient flight data. Some of the foundations of the concepts used can be implemented into legacy flight data tools. It can apply to all areas of aviation concerning safety, commercial and private, large and small aircraft, military and civilian.

The application can also extend to other industries, with the SVETLANA project algorithms being successfully used in the medical environment for patient monitoring and prediction systems in real time[45].

3.10.3 Potential impact of technology

Successful implementation of this technology can provide a host of benefits for not only the air transport sector, but many sectors that use data due to the standardised, comparable nature of the tools. These benefits include a reduction in the efforts to maintain legacy algorithms as smarter, more robust models are implemented.

This technology can support standardisation that enables seamless integration with current technologies whilst still supplying more features. Due to standardisation, less time will be required training operators as the environment will not change.

Better automation can occur as less input is needed from operators, with regards to both air traffic control and flight data analysis.

3.10.4 Alignment of technology with EU transport policy

The 2011 White Paper goal of a modernised traffic management infrastructure can directly benefit from the MALORCA project that uses speech recognition systems to reduce air traffic controllers' work, with the potential to help arrival managers at specific airports.

The Single European Sky (SES) is an initiative launched by the European Commission in 2004 to improve air traffic safety and the performance of air traffic management systems[46]. Some of the main objectives of this

[44] https://www.ecfr.gov/cgi-bin/text-idx?node=14:1.0.1.3.11#ap14.1.25.0000_0nbspnbspnbsp.o
[45] https://cordis.europa.eu/article/id/91249-making-better-use-of-flight-data-from-aircraft

initiative are to halve the cost of air traffic management, improve safety by a factor of 10 and reduce the environmental impact of each flight by 10%. Research into this technology can help to reduce the overall costs of air traffic management systems through automation as well as increase safety.

3.10.5 Market drivers and readiness for technology

With a recent push for improvements in aircraft safety, this technology will likely be integrated quickly. The fact that it can be implemented immediately into legacy equipment makes the transition even more attractive. With the flight data monitoring market looking to grow from $3.45 billion in 2016 to $5.34 billion by 2022 this subsection can also be expected to grow as much[47].

3.11 Technology 11 – Battery management system module

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
8	€28,714,367	Research		ELT, VDM

Battery-electric vehicles (BEVs) have large batteries that need to be managed effectively to monitor their state-of-charge (SOC) and prevent damage to the battery. Battery management system (BMS) modules are electronic devices that allow for the monitoring of SOC, temperature (to prevent overheating) and control over individual cells within the battery pack.

A battery management system can report on the following items:

— Voltage, current and coolant flow;

— Temperature;

— SOC;

— State-of-health (SOH); and

— State-of-power (SOP).

A battery management system can also control the recharging of the battery via regenerative braking to ensure that this is delivered to the battery in a safe manner.

3.11.1 Development of technology to date and current status

Recent research projects are focusing on control systems to allow for ultra-fast charging (350 kW) as well as the effective thermal management of the batteries. Perhaps the key area of BMS research is the balancing of the cells: the discharge of small amounts of power from individual cells or small groups of cells to ensure that the overall pack capacity can be maximised and not constrained to the capacity of the weakest cell.

3.11.2 Potential application of technology

In practice this technology will just be added into the vehicles at the manufacturing stage, with the end-user able to see the benefits immediately. It will be the vehicle manufacturers' responsibility to ensure that all new battery vehicles are equipped with BMS modules.

The end-user will be able to view the battery health report through the vehicle's dashboard. This will enable users to ensure that the battery's overall health is good before and during journeys and hence the number of breakdowns will reduce.

[46] https://ec.europa.eu/transport/modes/air/ses_en

[47] https://www.marketsandmarkets.com/Market-Reports/flight-data-monitoring-market-117613618.html

3.11.3 Potential impact of technology

This technology can effectively monitor and manage battery health, resulting in a potential longer lifetime of a battery. As battery replacements can be expensive (Nissan leaf battery replacement can cost £4,920[48]) there will be significant benefits from extending the lifetime of a battery.

Battery management will become particularly necessary for older and second-hand BEVs. A brand-new vehicle is not available to everyone, and so with the increasing uptake of BEVs will come increasing uptake of second-hand BEVs. These will require optimal battery management to ensure the maximum lifetime of the battery is achieved.

3.11.4 Alignment of technology with EU transport policy

This technology could increase the attractiveness of new and older BEVs; helping to remove conventionally fuelled vehicles from the road. This is because the battery lifetime can be increased by implementing this technology; helping to ease fears of potential battery replacement. The increased attractiveness of BEVs will help to achieve CO_2 reduction targets for new cars and vans in line with the performance standards for cars and vans post-2020 policy[49], due to the zero CO_2 tailpipe emissions from BEVs.

The subsequent increased use of electric vehicles (EVs) will help to reduce the amount of air pollution in urban areas caused by road transport and contribute to achieving the European Green Deal's 90% reduction in transport CO_2 emissions targeted for 2050.

3.11.5 Market drivers and readiness for technology

The global battery management system market is forecast to grow from $5.2 billion in 2019 to $12.6 billion by 2024[50]. This growth is accelerated by the uptake of electric vehicles. BMS technology is particularly appealing for vehicle manufacturers. This is because battery management system modules allow for a longer battery lifetime, meaning that fewer battery replacements are needed reducing overall lifetime cost of an electric vehicle. However, reducing the number of required replacements may see some resistance from battery manufacturers themselves. This is because fewer replacements means ultimately less demand for batteries, and hence less income for battery manufacturers.

As some areas of battery management have already been implemented, there are no barriers to the market readiness of the technology.

3.12 Technology 12 – EV component modelling tools

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
5	€28,119,514	Research		ELT, VDM

Electric vehicle (both BEV and FCEV) component modelling tools are technologies that allow for the integration of virtual and real-world testing for all types of electric vehicles and their components in the design phase.

This technology can consist of complex and accurate simulations of various EV components, allowing for virtual testing to replace real-world testing in some cases. This technology can also provide a standardised model for a number of EV components, allowing for the widespread adoption and development of the modelling tools.

Current modelling of EV components may be different across all manufacturers, meaning that some models are more efficient and more reliable than others. This can result in some testing of EV components to be sub-optimal and would benefit from a set of standardised models that can be used by any manufacturer to give accurate and fast testing of EV components.

[48] https://www.batteriesontheweb.co.uk/nissan-leaf-replacement-battery/
[49] https://ec.europa.eu/clima/policies/transport/vehicles/regulation_en
[50] https://www.marketsandmarkets.com/PressReleases/battery-management-bms.asp

3.12.1 Development of technology to date and current status

Whilst there have been some standards developed for virtual component modelling (e.g. FMI[51], ASAM XiL[52]), modelling tools are typically created and managed in a fragmented manner. This creates duplicated effort, as models of the same component or system are re-created several times. Examples of EV component models include battery models to simulate battery SOC and SOH, and electric-motor models to test efficiency and power density of the electrical motor. There is also research being undertaken to ensure that each individual modelling component integrates optimally with the overall vehicle-level simulation.

The current projects researching this technology are typically focused on creating a standardised model for systems or sub-systems, which can then be reproduced by a number of industrial manufacturers. For this reason, the partners consist of engineering and technology companies, universities and automotive manufacturers.

3.12.2 Potential application of technology

In practice, this technology could be a virtual model of an electric vehicle component, or a set of components, which allows for different tests to be undertaken to see the effect on the component and to ensure that all components will work together as intended. This will potentially remove the need for real-life testing of certain systems.

3.12.3 Potential impact of technology

EVs offer a route to decarbonisation for road transport. For EVs to be a viable mass-market option, they must be able to be manufactured and tested in a short time-frame. Current EV component testing is not optimal due to the fact that many of the tests are conducted with real hardware, when they could be modelled and tested in a virtual environment. This can result in higher costs and longer overall testing times. EV component modelling tools could allow for a transition from real-world testing to virtual testing, reducing the overall testing time for components. This technology also may allow for re-use of models that could allow for complex EV component development.

A project researching EV component modelling tools has a target to reduce the overall time-to-market for electric vehicles by 20% by harmonising the interaction between the models.

3.12.4 Alignment of technology with EU transport policy

The technology could allow for an improved time-to-market for electric vehicles, and hence accelerate their market uptake in Europe. This will help towards the policy goal of reducing 'conventionally-fuelled' cars in urban transport and provide a route for road transport decarbonisation.

The subsequent increased use of electric vehicles will help to reduce the amount of air pollution in urban areas caused by road transport and go some way to achieving the 90% reduction in transport emissions targeted for 2050 in the European Green Deal.

3.12.5 Market drivers and readiness for technology

It is expected that automotive manufacturers will drive the adoption of this technology, as they will benefit from the decreased time-to-market and real testing required for EVs and their components. As EV components are already required to be tested, the market is ready for this technology to be implemented.

With a primary aim of this technology being a standardised method of virtual testing of EV components, there may be some resistance from vehicle manufacturers that already have their own testing processes in place. This is because the manufacturers that see their testing as optimal may not like to see their competitors have access to models that they have spent time and money developing themselves.

[51] https://fmi-standard.org/
[52] https://www.asam.net/standards/detail/xil/

3.13 Technology 13 – Electric propulsion system for vessels

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
3	€28,071,429	Validation		ELT

An electric propulsion system for vessels uses electrical energy to power the propeller of a boat; this can be from a small fishing boat all the way up to a commercial ferry or cruise ship. Most modern ships are powered by large diesel engines and have been so for more than 100 years. Environmental concerns are driving the search for alternative propulsions systems and, as for road vehicles, electric power is an attractive option. The electric power can come either from batteries that are recharged on shore, or electric cables that are attached to the vessel throughout its journey, either overhead or submerged. The electric cable system is generally used for short, straight ferry trips, as such operations have little need to manoeuvre or to divert their course. There would be significant challenges to creating and maintaining an ultra-long cable-based electric supply system for long trips or ones that need to take variable routes. The use of a battery electric system also creates a potential opportunity to have a completely self-sufficient vessel that uses a self-generating propeller, a propeller that exploits the energy obtained from wind propulsion when the vessel is under sail.

The project concentrating on developing this technology is looking specifically at replacing small and medium-sized diesel engines, as it has identified that electric propulsion systems are already available for larger vessels. It also concentrates on utilising a battery system combined with hydropower as opposed to electric cables.

3.13.1 Development of technology to date and current status

The MarketStudy-OV (market research for oceanvolt zero-carbon emission marine electric propulsion system) project is a feasibility study looking a potential new markets for electric propulsion technology, funded by the SME-1 action under H2020. The study co-ordinators Oceanvolt Oy already supply electric and hybrid motor systems; their technology currently operates in the medium sized daysailer and larger catamaran markets; they claim to be the number one global provider in these markets. Oceonvolt's system uses a hydropower propeller to create energy whilst sailing; it is silent, lightweight and maintenance free. One of the propellers they currently manufacture generates 1 kW of energy when the boat is travelling at 7 to 8 knots and 3 kW at 11 to 12 knots, this can be fitted on any sailboat between 20 ft and 60 ft, old and new[53].

The MarketStudy-OV project aimed to identify two or three new markets with the potential for significant growth that could use the existing products with little to no modifications. This involved running workshops with company management team and key board members, performing customer interviews and running a data search. After completion, they found commercial workboats and small ferries to be the best new markets available, with a predicted total market size of €4 billion by 2024[54]. The adjustments required to the current technology are relatively small, with a suitable product ready for launch in one year. This project finished in April 2017 and the technology has since been fitted in one small electric ferry, the solar electric Secret 33. This 9.9 m ferry uses a 15 kW motor powered by solar panels[55].

The Port-Liner zero-emission ships for inland waterways project is aiming to build six inland waterway vessels capable of transporting shipping containers; driven using E-Powerboxes, a system of batteries providing 1.6 MW of power. The partners are planning on using vanadium redox flow batteries, which are safer, more scalable and longer lasting than lithium ion batteries; these batteries are currently at TRL 7, so research into these has delayed the development and delivery of the vessels[56]. Once completed they will operate between the ports of Amsterdam, Antwerp, Duisburg and Rotterdam[57]. To date they have identified two concept ships, the EC52 and EC110, the latter having 8% more capacity than a conventional ship due to the electric propulsion system releasing the space that an engine room would have previously taken. It will have a duration of more than 30 hours, allowing it to easily cover the mentioned ports.

[53] https://oceanvolt.com/solutions/systems/servoprop-sail-drive/
[54] https://cordis.europa.eu/project/id/744658/reporting
[55] https://oceanvolt.com/testimonials/solar-electric-secret-33/
[56] https://www.schuttevaer.nl/nieuws/dossiers/groen_ondernemen/2019/09/25/port-liner-krijgt-flow-batterijen/
[57] https://trimis.ec.europa.eu/project/port-liner-zero-emission-ships-inland-waterways

The ACCEL BARGE (accelerate electrification of inland waterways) project is looking at vessels, infrastructure and power supply equipment for the electrification of inland waterways. It aims to initially produce six zero emission inland waterway container vessels, then five multipurpose barges alongside four extra-wide container vessels. None of these have currently come to fruition but the project was expected to finish in March 2020. It has total funding of €28 million with €5.6 million being provided by the EU under the CEF Transport programme. This project is by far the largest, receiving 99.7% of the overall funding looking at this technology.

3.13.2 Potential application of technology

This technology can be implemented in numerous ways, for immediate effect the propellers can be fitted into sailing ships already in service; in the long-term new ships can be built with these propellers already fitted. It will take longer for the full electric propulsion systems to gain significant penetration in the maritime fleet, but they can be used for larger container ships, unlike the retrofitted power-generation propellers. The electric vessel infrastructure could be installed at all ports, within the EU and globally, assuming electric vessels will use similar battery charging systems.

3.13.3 Potential impact of technology

Using electric motors instead of diesel engines can have a dramatic impact if uptake is widespread, resulting in significant reductions in CO_2, NO_x, and particulate matter. For example, if 120,000 diesel engines were replaced with electric propulsion systems, CO_2 emissions would fall by 607,000 tonnes a year, the equivalent of 160,000 cars annually[58].

There could also be a reduction in the cost of transporting goods and people because of the higher efficiency and reliability of electric motors; this could result in cheaper prices for consumers and/or a more reliable service. Owners of the vessels can also benefit as the total cost of ownership falls, largely due to the lower maintenance and operating costs coupled with the low price of electricity. Oceonvolt estimates a payback time of 12 to 24 months for its products, along with an expected lifetime three times larger than diesel engines[59].

A reduction in noise could have many benefits not just to citizens but also marine life, and with estimates of a 95% noise reduction those benefits could be substantial.

3.13.4 Alignment of technology with EU transport policy

Using electric vessels will go a long way to help reduce CO_2 emissions from maritime bunker fuels by 40%. It can also help with the 90% reduction in transport emissions goal and that of shifting road freight to inland waterways as more economically viable options become available. This technology can play a vital role in the reduction of pollution in EU ports as targeted by the European Green Deal.

The International Maritime Organization (IMO) focus on issues at an international scale, rather than being EU based, but they still have targets in place to reduce the total annual GHG emissions by at least 50% by 2050. This technology would significantly help to achieve this goal with the potential to have carbon-neutral vessels[60].

3.13.5 Market drivers and readiness for technology

A version of this technology is already in use in inland and coastal waters, so expanding it further to different size vessels should be feasible. The larger vessels will take longer to come into production and service, as more infrastructure is required compared to the possible retrofitting of smaller vessels. Torqeedo and ZF are currently cooperating on similar technology with plans to reach the market by the end of 2020[61].

58 https://cordis.europa.eu/project/id/744658/reporting
59 https://cordis.europa.eu/project/id/744658/reporting
60 http://www.imo.org/en/MediaCentre/HotTopics/GHG/Pages/default.aspx
61 https://www.electrive.com/2020/01/20/torqueedo-and-zf-to-cooperate-on-marine-vessels/

3.14 Technology 14 – Collision avoidance system

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
6	€25,739,032	Research		CAT, NTM, VDM

A collision avoidance system is a tool used to improve the safety of vehicles by either preventing or reducing the severity of a collision; this can range from a warning signal to the driver of a potential collision to an automated avoidance of the collision without the need for driver input. Collisions are generally detected using radar, lasers or cameras, although a combination of all of these can also be used. GPS sensors can also be used to highlight permanent obstacles and fixtures from a known database.

There can be different solutions to collision avoidance given the different uses. Research in aviation focuses on collision avoidance for commercial aviation, remotely piloted aircraft systems, avoidance for specific operations, such as parallel approaches to runways, as well as general aviation. Other research has looked at radar tracking systems in road vehicles and at implementing a moving part for controlling the vehicle.

3.14.1 Development of technology to date and current status

The PJ11 CAPTO (enhanced air and ground safety nets) project has focused on researching the requirements for five different solutions in the aircraft industry: one on ground safety procedures (particularly a short-term conflict alert), and four others for airborne collision avoidance systems (ACAS): commercial use, remotely piloted aircraft systems, specific operations and general aviation[62]. ACAS are used around the world, so interoperability is key, along with compatibility with existing systems.

Most of the systems mentioned in this project are approaching the demonstration phase of testing [63]. This project had a total budget of approximately €15 million, with about 33% being provided by the H2020 'Smart, Green and Integrated Transport' programme.

The ARTRAC (advanced radar tracking and classification for enhanced road safety) project aimed to develop an economical safety system for vulnerable road users, consisting of actuators to control the vehicle and radar sensors to assess the vehicle surroundings. The project initially analysed accident statistics and existing sensor technology. They then developed the sensor hardware, algorithms, on-board interfaces and software and integrated them into a test vehicle. The project produced a cost-effective 24 GHz radar sensor that monitors road conditions and vulnerable road users, with automatic braking and steering implemented to prevent accidents[64]. It was a unique project because it used just radar imaging, making it far cheaper than the usual radar and optical combination used in other cars. This project had funding of about €4 million with 70% being provided by the EU under the FP7 Transport programme.

The SENSORIANCE (sensorial awareness system for obstacle detection and collision avoidance) project aims to develop high-definition vision capabilities in the Infrared (IR) and visual spectra with a comparatively low cost; this can aid pilots in all flight phases and in all weather conditions. The project has selected the visual and IR spectra as optimal due their ability to work during adverse weather conditions, with long wavelength IR (LWIR) having a low absorption through water vapour. Hardware and software modules have been defined leading to the pipeline of environment sensing with visible, near IR and LWIR producing video streams that are then fused into one image before being sent to an output such as a head-up display. This project had EU funding of approximately €1 million (from the H2020 'Smart, Green and Integrated Transport' programme) out of a total budget of approximately €1.5 million.

3.14.2 Potential application of technology

The capabilities offered by this technology would be useful for almost every vehicle and, with slight adjustments, the technology could be implemented in all vehicles. Sensors can be, and are already being, added to cars on the road; these currently warn the driver of hazards, with some automatically performing manoeuvres to avoid them, but they could be expanded to allow for more autonomous driving. These same sensors can be fitted to all road vehicles from scooters to trucks.

[62] https://cordis.europa.eu/project/id/732996
[63] https://cordis.europa.eu/project/id/732996/reporting
[64] https://cordis.europa.eu/article/id/150881-cuttingedge-technology-for-cars-to-detect-pedestrians

Sensors can also be used by aircraft, not only for detecting other aircraft to avoid collisions, but also providing visual information for pilots in adverse weather conditions to safely take off and land aircraft. They can be used by all types of aircraft with retrofitting possible.

3.14.3 Potential impact of technology

With more sensors and collision avoidance systems in road vehicles accident rates could drastically fall. Using just radar sensors as effectively as combinations of radar and visible spectrum sensors allows for a much cheaper solution, increasing the rate of uptake. With more cars using sensors they can become more autonomous, potentially resulting in more efficient driving and reductions in congestion.

Visual sensors for aircraft can increase safety level in inclement weather, when accidents are most likely to occur. Current technology uses mid-wave IR sensors that need to be cooled with liquid nitrogen to produce adequate images, these are heavy, expensive, require considerable maintenance and have significant cooldown times before operation can begin[65]. Using multiple wavelengths allows for lightweight, low power, cost-effective sensors, encouraging increases in uptake. The technology itself will allow for fewer flight delays, missed approaches, forced alternative routes and a decrease in hold times, all resulting in less fuel burn and a reduced environmental impact.

3.14.4 Alignment of technology with EU transport policy

Sensor technology can help the 2011 White Paper objective of deploying a modernised air traffic management infrastructure, as they allow for more automation on the ground and fewer accidents. Moving closer to zero fatalities in road transport will be more achievable with less human error and more smart automation of vehicles that automatically avoid collisions, helping to achieve the European Commission 'Vision Zero' strategy of a 50% reduction in fatalities by 2030 and zero deaths by 2050[66].

The EU have also adopted the ruling that, by 2022, all cars and vans must have advanced emergency braking systems along with emergency lane-keeping systems. The technologies investigated will make this easier to achieve, with efforts to produce cost-effective solutions that can be retrofitted into older vehicles[67].

This technology can also greatly improve the safety of aircraft, a key goal in the SES initiative which looks at improving safety by a factor of 10.

3.14.5 Market drivers and readiness for technology

Sensors and collision avoidance systems are already in place on many vehicles, implementing improved sensors should not present any significant problems. Many of these sensors can be retrofitted and so the need to produce a whole new vehicle is not required, increasing the rate of penetration in the on-road fleet.

3.15 Technology 15 – Nanomaterials for structural health monitoring

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
1	€25,356,214	Research		VDM

Structural health monitoring (SHM) uses damage detection systems, often built inside the structure, capable of relaying information to a user who can identify any damage and assess its severity. This damage can be a physical change in the geometry of the structure, or internal to the materials from which the structure is constructed. If undetected, small elements of damage can grow rapidly, leading to catastrophic failure in extreme cases.

Nanomaterials are materials built up from a tiny scale, between 1 and 100 nanometres. These materials can have beneficial properties compared to their counterparts, such as increased strength to weight ratio or higher levels of electrical conductivity.

[65] https://cordis.europa.eu/project/id/785315/reporting
[66] https://ec.europa.eu/transport/themes/strategies/news/2019-06-19-vision-zero_en
[67] https://www.consilium.europa.eu/en/press/press-releases/2019/11/08/safer-cars-in-the-eu/

The project that is investigating this technology is specifically looking at using nanomaterials in structural health monitoring systems to create aircraft wings that can aerodynamically morph. This involves the physical wing geometry changing during flight to optimise flight efficiency and provide aerodynamic control; health monitoring sensors would provide information on the shape of the wing to ensure aerodynamic benefits and failure tolerance of the wing structure to ensure its structural integrity.

3.15.1 Development of technology to date and current status

The SARISTU (smart intelligent aircraft structures) project aimed to reduce air travel costs, from both a manufacturing and operational perspective. It aimed to achieve this through a combination of reduced aircraft downtime from unscheduled inspections, reduced fuel burn through drag and weight reductions, and reduced manufacturing times of advanced fuselage structures.

SARISTU did perform tests on morphing technologies applied to wing structures, although it found real world applications would not currently be possible due to the requirements for high levels of stiffness conflicting with the active deformation ability. However, it did show that if this technology was to be adopted, fuel consumption could be reduced by 6.5%, whilst also reducing flight path noise by up to 8 dB. The latter benefit was not verified experimentally by the SARISTU project, but was identified through the close similarity to the aerodynamic changes investigated in another project[68].

SARISTU looked at integrating structural health monitoring sensors in the fuselage to immediately assess any damage, significantly reducing inspection delays. The team managed to achieve a cost reduction in inspections of 1.33% for carbon fibre fuselages. They also experimented with carbon nanotubes in the skin-stringer-frame structure system and were able to improve the structural robustness or reduce the structural weight by 2.2%. This did fall short of the 3% objective, but weight savings of 5% could be possible if the nanotubes' electrical conductivity was exploited, leading to a lower requirement for cabling[69].

The electrical conductivity of carbon nanotubes can be used for low level electrical functions, but with further technological integration, higher level functions could be possible, such as electrical grounding or bonding. This could result in a 15% cost reduction of fuselages on top of weight reductions, although this project only realised a 4% cost reduction. The difficulty lay in complex benchmarks and the 4% improvement was only calculated from weight saving benefits as it was not possible to factor in installation cost savings, so this was considered to be a highly conservative estimate[70]. This project had a total budget of almost €51 million, including EU funding of nearly €32.5 million from the FP7 Transport programme.

3.15.2 Potential application of technology

This technology can bring benefits well beyond the aircraft industry, conformal morphing can be applied to any aerodynamic surface, so it may find applications in other types of vehicles and moving machine parts used in manufacturing industries or other machinery with fluid control systems.

Structural health monitoring can also be applied to sectors outside of aviation, especially if weight is a key factor. With regular inspections of many structures being time consuming and costly, not to mention difficult with some modern composite materials not showing signs of wear, structural health monitoring can improve these costs by providing accurate and instant readings for the health of almost any structure.

The electrical properties of carbon nanotubes can be used in many other industries too, with the potential to generate and transmit data from one single structure.

3.15.3 Potential impact of technology

If this technology were to be adopted by the aircraft industry, fuel consumption could fall by 6.5% from the morphing technology alone. With weight reductions of 2.2% from nanomaterial structures used in the fuselage and a further 2.8% weight reduction when utilising the materials electrical properties fuel consumption would fall even further. This same weight saving can be applied across the whole aircraft structure for even greater improvements.

[68] https://cordis.europa.eu/project/id/284562/reporting
[69] https://cordis.europa.eu/project/id/284562/reporting
[70] https://cordis.europa.eu/project/id/284562/reporting

Costs of aircraft could also fall substantially with inspection cost already improving by 1.33%. Electrical structure network installation costs could fall by up to 15%.

With 2.2 billion people flying every year, the 8 dB fall in air traffic noise could contribute significantly to reducing noise pollution, especially in neighbourhoods near airports[71].

3.15.4 Alignment of technology with EU transport policy

This technology can increase the fuel efficiency of aircraft that aligns with the European Green Deal aim of reducing transport emissions by 90%, this will in turn help to improve the air quality near airports.

The carbon offsetting and reduction scheme for international aviation (CORSIA) aims to keep net CO_2 emissions no higher than 2020 levels, requiring airlines to monitor emissions on all international routes and offset emissions above 2020 levels from routes included in the scheme. Work is ongoing to make this scheme operational, at which point this technology can help by increasing the fuel efficiency of aircraft.

3.15.5 Market drivers and readiness for technology

The aviation industry is constantly challenged to reduce its environmental impacts, both from the need to contribute in the overall decarbonisation of transport but also because fuel costs form a high percentage of total operating costs for airlines. The need for efficient aircraft coupled with the industry growth means any fuel and cost savings could be highly beneficial. Even though aircraft have lifespans of up to 30 years, the growth of the industry requires more to be built, so whilst the technology could be difficult to retrofit into in-service aircraft, there is considerable potential for its inclusion in new aircraft deliveries.

3.16 Technology 16 – Hydrogen storage system

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
7	€22,600,042	Research		ALT, INF, ELT, VDM

Hydrogen used as a transport fuel is seen as a potential way to decarbonise all forms of transport. Hydrogen can be produced via an electrolysis process. If the electricity required for the process is produced from low-carbon sources, then the hydrogen produced is also low-carbon. Hydrogen can be used as a fuel in two ways, either burned as a gas within an internal combustion engine (ICE) or used to power a fuel cell to generate electricity. If the hydrogen is used within a fuel cell, then the tailpipe emissions (of CO_2 and emissions related to air quality impacts) will be zero.

Hydrogen has the highest energy per unit mass of any fuel; however, its low density at room temperature results in a lower energy per unit volume. Therefore, to improve the energy volume density, advanced hydrogen storage methods are required. This can include numerous methods, with the most common storage approach being either compressed as a gas or cooled to a liquid form. To use these storage methods, either very high pressures (over 700 bar) or very low temperature (less than -200°C) are required.

There are new hydrogen storage systems being explored, often referred to a 'material-based' storage techniques. These are composed of methods such as liquid organic hydrogen carriers (LOHC), which chemically bind with the hydrogen, making it easier to store and transport. The storage challenges associated with hydrogen are relevant to both on-board storage of hydrogen as well as storage of hydrogen at refuelling stations.

3.16.1 Development of technology to date and current status

To date there has been substantial research in the field of hydrogen storage. As mentioned above current hydrogen storage methods are already developed, particularly for compressed and liquid hydrogen.

Recent projects have been exploring ways to chemically bind hydrogen to other substances (LOHCs) that increase the chemical stability and density of the hydrogen making it easier to transport. Using LOHCs eliminates the need for high-pressure containers, and the hydrogenlogistics project is aiming to demonstrate

[71] https://cordis.europa.eu/article/id/36614-smart-design-and-nanotechnology-to-cut-aircraft-operational-costs

LOHC-stored hydrogen by distributing it to a commercially operated hydrogen refuelling station in Finland. This would raise the current development phase of the technology beyond research.

3.16.2 Potential application of technology

In practice this technology would be directly implemented into vehicles and refuelling stations. It would allow for improved hydrogen vehicle safety and driving range, as well as increased capacity for the hydrogen refuelling stations.

3.16.3 Potential impact of technology

The benefits of improved hydrogen storage will allow for a higher energy (by volume) to be carried both at refuelling stations and on-board the vehicles. By using advanced techniques, such as LOHCs, the hydrogen can be transported and distributed more safely and in higher quantities. This will increase the driving range of FCEVs as well as increasing the refuelling capacity of hydrogen refuelling stations (reducing the frequency at which they must be replenished). It will also increase the range of other transport modes (water, rail, air) if hydrogen is to be used as a fuel source.

One project (hydrogenlogistics) is researching a LOHC technology that can increase the storage capacity for hydrogen by up to five times that of the current storage methods. It is also stated in this project that the technology can reduce the operating cost of a hydrogen road vehicle by up to 80%. This is an ambitious target; however, current hydrogen storage and fuel is expensive and so the costs need to be reduced to make it a viable fuel for the future.

3.16.4 Alignment of technology with EU transport policy

This technology will help with the attractiveness of hydrogen powered vehicles in all transport modes. If the hydrogen produced has low upstream CO_2 emissions, then hydrogen vehicles will help towards achieving the European Green Deal objective of a 90% reduction in transport emissions by 2050. Improvements to hydrogen storage would mean improvements to hydrogen refuelling facilities, hence helping to achieve the European Green Deal objective of 1 million recharging and refuelling points for low and zero-emission vehicles across Europe by 2025.

If the hydrogen is used in fuel cells to generate electricity, then the tailpipe NO_x and PM emissions will be zero. This will help to achieve cleaner air, particularly in urban areas.

3.16.5 Market drivers and readiness for technology

The hydrogen storage market is expected to be worth $18.2 billion by 2024[72]. Therefore, there will be considerable demand for improved hydrogen storage in the future. This depends on the future policy on hydrogen as a fuel source. For road transport, battery technology might improve drastically in terms of energy density within the next 10 years enabling electric vehicles to have a high driving range. This would leave hydrogen for road transport as a less attractive option as current advantages of hydrogen over batteries is the increased driving range, particularly for HGVs.

The uptake of hydrogen powered transport is also dependent on the advances of hydrogen production methods. Currently, the most common method of hydrogen production is steam-methane reforming from natural gas, which is not a renewable source and has a high carbon footprint. If a 90% reduction in transport emissions is to be achieved by 2050 using hydrogen, then advances in electrolysis and renewable electricity production will be required to produce low-carbon hydrogen.

3.17 Technology 17 – Vehicle energy management systems

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
7	€21,910,902	Validation		ELT, VDM

[72] https://www.prnewswire.co.uk/news-releases/hydrogen-energy-storage-market-worth-18-2-billion-by-2024-exclusive-report-by-marketsandmarkets-tm--857817111.html

An internal combustion engine (ICE) vehicle produces residual heat, which can be used to warm up the inside of the vehicle. As BEVs do not have ICEs, there is no residual heat to use for cabin heating in cold weather. This means that the energy for climate control comes directly from the battery in cold weather (heating) as well as in hot weather (cooling/air conditioning). As batteries for electric vehicles have limited energy storage, it is critical that the energy is managed effectively to maximise the driving range of the BEV.

The impact of cabin heating, ventilation and air-conditioning (HVAC) can lead to a 50% loss in driving range for a BEV through heating the cabin in the winter and cooling the cabin in the summer[73].

Vehicle energy management systems can be based on a material composed of electrically conductive and non-conductive fibres that is integrated within the vehicle structure. This material allows for direct and fast heat to the passengers in winter months. Many BEVs use resistance heaters to warm the cabin; these are effective but require lots of electricity. Heat pumps are more efficient than resistance heaters, although they are typically more expensive. In summer months, air is cooled and dehumidified based on a vapour compression cycle (VCC) that cools air below the temperature at which condensation beings to occur (dew point). A VCC is the currently available technology for air-conditioning in BEVs.

3.17.1 Development of technology to date and current status

Current vehicle cooling systems are based on a VCC, as explained above. New technologies are exploring the possibility of using desiccants to dehumidify air without cooling it below its dew point; as being researched within the project XERIC. This process is more energy efficient, as well as allowing separate control of temperature and humidity. Within the project XERIC a working prototype was developed for a cooling system using a liquid desiccant cycle; with the technology beginning to reach the higher development phases.

In terms of cabin heating, a textile has been developed during the MAXITHERM 2 project that can dissipate heat homogenously across a surface. This technology allows for temperatures to be set independently for each area of the vehicle to suit passenger's preferences. This technology is currently at the validation phase, with testing under real driving conditions yet to be undertaken.

3.17.2 Potential application of technology

The vehicle energy management technologies described above would be implemented directly into the vehicle's architecture. This would be the responsibility of the vehicle manufacturers. The users would then see the benefits of the increased driving range as the technology is implemented directly into the vehicle, together with greater comfort (and reduced concern that selecting a more comfortable cabin environment would restrict their driving range).

3.17.3 Potential impact of technology

The climate control technologies for electric vehicles have the potential to reduce the overall energy consumption of climate control systems on the vehicle's battery. This would result in an increase in driving range under real-world conditions and an increase in the overall attractiveness of owning a BEV.

One research project has stated that alternative heating systems for BEVs can reduce electricity use by 30% when using climate control. This energy would be saved by the battery and hence increase the real-world driving range. In addition to increased driving range, the end-user would also see monetary savings by using less electricity, particularly during the summer and winter months.

3.17.4 Alignment of technology with EU transport policy

Vehicle energy management systems can increase the attractiveness of electric vehicles by offering a higher real-world driving range when using climate control. This could increase the uptake of BEVs and reduce the overall number of conventionally fuelled cars on Europe's roads.

The subsequent increased use of electric vehicles will help to reduce the amount of air pollution in urban areas caused by road transport and go some way to achieving 90% reduction in transport's CO_2 emissions by 2050, as set out in the European Green Deal.

[73] https://www.sae.org/news/2018/05/new-bev-thermal-optimization-studies

3.17.5 Market drivers and readiness for technology

Improving the real-world driving range of BEVs will increase the overall uptake of BEVs. This makes vehicle energy management systems an attractive technology for vehicle manufacturers as well as research institutions. The global automotive climate control market is expected to reach around $24 billion by 2023[74]. Whilst this value includes climate control for conventionally fuelled vehicles, it can still be said that climate control and hence vehicle energy management systems will have a large market value as the world shifts from ICEs to BEVs.

Although improved driving range for electric vehicles ultimately decreases the energy consumption and therefore costs, it is currently unclear what the exact costs of implementing this technology are. In some cases, the overall cost of adding vehicle energy management systems to electric vehicles is high[75]. This may force vehicle manufacturers to increase the overall price of the vehicles, which would reduce the attractiveness of purchasing an electric vehicle.

3.18 Technology 18 – Computer simulations modelling climatic impact on Arctic marine transportation

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
2	€21,574,964	Research		NTM, VDM

This technology will use computer simulations to model the impact of climate change on Arctic marine transportation. Arctic climate predictions are quite accurate when looking at the short term (yearly) and much longer term (several decades), but they are much poorer when looking at the intermediate scale. The system is highly non-linear due to different impacts of sea ice, the ocean and atmosphere that cause significant variability making these predictions harder.

The evolution of the Arctic climate will have a critical influence on its marine ecosystems and human activities; this technology will use impact evaluations on fisheries, marine transportation, marine mammals and the extraction of hydrocarbons to highlight implications across sectors and to form a final unified evaluation of the socio-economic impact of climate change[76].

This technology will also focus on the safety of ship navigation in the Arctic using a combination of; augmented reality to improve situational awareness and decision making, real time meteorological and oceanographic data for safe route optimisation, vessel design tailored for use in Arctic conditions, and providing fuel to these ships[77].

3.18.1 Development of technology to date and current status

The ACCESS (arctic climate change, economy and society) project investigated the interactions between human activities and climate change, specifically in the Arctic. ACCESS evaluated the impact on marine shipping and found that benefits from the shorter journeys, by travelling directly through what would have been ice, would result in significant financial savings. Although this will depend on the ice conditions and any resulting infrastructure along the Northern Sea Route. They found that in the medium-term traffic levels are unlikely to change but in the long-term, if ice-free, travel will increase significantly, and new routes may be created[78].

With regards to fisheries, changes in plankton biomass and distribution could be expected, although the uncertainties are large and global markets are likely to have a larger impact. Changes in policy, conflicts of interest and the behaviour of coastal communities could play a large role in the global market of Arctic seafood.

[74] https://www.prnewswire.com/news-releases/global-automotive-climate-control-system-market-research-report---forecast-to-2023-300631519.html
[75] https://www.researchgate.net/publication/325536892_The_solutions_to_electric_vehicle_air_conditioning_systems_A_review
[76] https://cordis.europa.eu/project/id/265863
[77] https://cordis.europa.eu/project/id/723526
[78] https://cordis.europa.eu/project/id/265863/reporting

ACCESS found that, if offshore production of hydrocarbons increased, the effect would be minimal in Europe, with Asia receiving most of the production.

ACCESS has produced three management tools: a Marine Spatial Planning tool for the whole Arctic, a framework for integrated Ecosystem Based Management, and a set of sustainable development indicators[79]. These tools offer an informed, non-political, global system to be used for planning strategies and responding to unexpected events. ACCESS received funding of approximately €15 million with EU contributions amounting to almost €11 million from the FP7 Transport programme.

The SEDNA (safe maritime operations under extreme conditions: the Arctic case) project has developed a novel approach to risk-based ship design using Bayesian modelling of accident data. They have also made active and passive anti-icing solutions to be implemented by ships. They produced an augmented arctic ship bridge that provides live, visible updates of routing and weather information; this can use the Meteorological Office's world-leading weather forecasting models, made possible with the data gathered from this project. They have created a report to support safe Arctic navigation and they built prototypes of weather data that can be used by route makers[80]. This project had an EU contribution of approximately €6.5 million (from the H2020 'Smart, Green and Integrated Transport' programme) out of a total funding of €6.7 million.

3.18.2 Potential application of technology

This technology can be used by parties involved in business around the Arctic to gain a clearer understanding of the future and make informed plans taking account of the effects of climate change. The improvements made in weather tracking are already being used by MET weather; they can inform locals of any weather to be cautious of with more confidence.

With more accurate predictions of the conditions in the Arctic, a major concern when it comes to global warming, policy makers have more evidence to base their decisions on. Policy on a local level may also be influenced by the extra knowledge on marine life and fisheries. Shipping routes will be easier to plan as the technology will provide more accurate modelling of ice levels.

The augmented reality aspects can be used in many different industries; with cars already having head-up displays, offering extra visual information on hazards could become a possibility. The anti-icing engineering solutions could also be applied to certain other vehicles, articulated trucks often travel long stretches in icy conditions and could benefit from this technology.

3.18.3 Potential impact of technology

The impact could potentially be very significant with effects on the marine and terrestrial ecosystems, and human activities leading to large consequences across Europe. By assessing the current situation this technology has created guidelines for governance to the Arctic that could help to reduce exploitation of its natural resources and prevent further damage the environment.

Shipping efficiency can also be greatly improved as weather forecasts are more accurate allowing for better route planning. The ship technology also allows them to travel more safely, with anti-icing properties protecting the physical vessel and the augmented reality providing manageable, key information on the surroundings. This can overall reduce the costs of shipping and reduce accident rates, which can be high amongst inexperienced ship members because of the extreme nature of Arctic travel.

3.18.4 Alignment of technology with EU transport policy

With more efficient shipping routes and information provided to guide sustainable policies this technology can contribute to reducing transport emissions by 90%, as targeted in the European Green Deal.

The 2016 EU Arctic policy has three main objectives; protect and preserve the Arctic, promote sustainable use of resources and economic development, and enhance international cooperation[81]. With more accurate simulations on the climate, better choices can be made in protecting and preserving it, aligning perfectly with one of the main objectives.

[79] https://cordis.europa.eu/project/id/265863/reporting

[80] https://cordis.europa.eu/project/id/723526/reporting

[81] https://ec.europa.eu/environment/efe/news/integrated-eu-policy-arctic-2016-12-08_en

The EU Maritime Information and Exchange system, SafeSeaNet, was established in accordance with the Vessel Traffic Monitoring & Information Systems (VTMIS) Directive. SafeSeaNet is a network for maritime data exchange using information from vessel traffic reports, satellite monitoring and Port State Control. This technology will help contribute to the available information and help to improve maritime safety, transport efficiency and marine environment protection.

3.18.5 Market drivers and readiness for technology

Augmented reality systems have since been tested on very large crude oil carriers with plans to release it on more ships, so the market is ready for this part of the technology[82]. Weather systems have been built using this technology, which again are already in use, although linking these weather system upgrades to shipping channels will take more time and planning.

3.19 Technology 19 – Electric ferry

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
1	€21,303,821	Validation		ELT

This technology looks at demonstrating the viability of a 100% electrically powered, emission free ferry. The ferry will be medium-sized and capable of carrying passengers, cars, trucks and cargo around island communities, coastal zones and inland waterways.

The innovative vessel will look at covering distances much larger than the current electric drivetrain ferries, which can handle just under 5 nautical miles between charges. This ferry technology will be able to travel over 10 nautical miles thanks to its record-breaking battery pack, capable of fast charging rates up to 4 MW[83].

This E-ferry design concept will also look at optimising the hull-shape as well as using carbon composite materials and lightweight equipment to increase efficiency further. Testing will be required to gain approval for the fire safety regulations of the new materials.

3.19.1 Development of technology to date and current status

The E-ferry (E-ferry prototype and full-scale demonstration of next generation 100% electrically powered ferry for passengers and vehicles) project spent the first four years focusing on the technological innovations necessary, building the structure of the vessel and then combining these elements together for inspection by the Class and Maritime Authorities to be approved. This process has now passed, and the E-ferry has been approved. Subsequently a crew have been trained to operate the ferry and it has entered into commercial service[84].

The E-ferry is single-ended and uses a simple roll-on roll-off drive-through approach to accept the potential 31 cars or 5 trucks on the open deck, it also has capacity for 147 to 196 passengers[85]. The 59.4 metre long ferry was constructed using a combination of lightweight materials, including a wheel house made of aluminium. The biggest weight saving came from the innovative electric propulsion and drivetrain system, which uses DC/DC convertor technology to replace previous heavy AC/DC convertors, which can now be positioned on shore rather than in the ferry.

This ferry is capable of covering the proposed routes, Søby to Fynshav and Søby to Fåborg, which are 10.7 nautical miles and 9.6 nautical miles respectively. It can also travel inland around the island of Ærø. To travel such distances, the world's largest battery with capacity of 4.3 MWh is on-board and when docked it automatically connects to a dual system of chargers running at 2 MW DC each. Due to such fast charging, the E-ferry only needs to be docked for 15 to 20 minutes[86]. This project received funding of over €15 million from H2020 'EU Framework Programme for Research and Innovation', out of a total of over €21 million.

[82] https://worldmaritimenews.com/archives/275417/mol-turns-to-augmented-reality-for-vlcc-navigation-systems/
[83] https://cordis.europa.eu/project/id/636027
[84] https://cordis.europa.eu/article/id/410195-all-aboard-fully-electric-ferry-completes-its-first-commercial-voyage
[85] https://cordis.europa.eu/article/id/410195-all-aboard-fully-electric-ferry-completes-its-first-commercial-voyage
[86] https://cordis.europa.eu/article/id/410195-all-aboard-fully-electric-ferry-completes-its-first-commercial-voyage

3.19.2 Potential application of technology

With a range of 22 nautical miles between journeys, this technology can be applied to many ferry routes currently in operation. Implementation in Denmark has already happened, after demonstrating the possibility to complete seven return trips per day between Søby and Fynshav other ferry companies' confidence will rise in the ferry and they may consider it for their own operations.

This technology could also be applied to smaller and larger shipping vessels with a few prior adjustments; the weight savings from the propulsion system and drive-train and keeping the AC/DC convertors on shore could easily be adapted for different sized vessels.

3.19.3 Potential impact of technology

The international shipping industry accounts for 2.5% of global GHG emissions, whilst in the EU 13% of transport GHG emissions come from the shipping sector[87]. It is estimated that over one year this single E-ferry will prevent the release of 2,000 tonnes of CO_2, 42 tonnes of NO_x, 2.5 tonnes of particulate matter and 1.4 tonnes of SO_2 into the atmosphere, this alone will bring great benefits but if this technology is adopted worldwide the benefits could be substantial[88].

Not only is the E-ferry environmentally friendly it will have lower running costs due to the low costs of electricity (in comparison with conventional fuels), this will benefit the operators and potentially consumers if the cost-savings are passed on. At the very least consumers can expect to see their travel times drop by 25% compared to their existing ferry routes[89].

The combined benefits to consumers and operators could result in socio-economic benefits to the local communities using this new technology, in addition to the environmental benefits as air pollution levels fall.

3.19.4 Alignment of technology with EU transport policy

The 2011 White Paper called for a reduction in EU CO_2 emissions from maritime bunker fuels by 40% and for 50% of road freight over 300 km to be shifted to waterborne transport; the E-ferry can help in both of these areas, as it produces no direct CO_2 emissions and can be used on inland waterways.

This also aligns with the European Green Deal reductions in transport emissions and a shift from road to inland waterway freight, as well as the reduction in pollution of EU ports. With a large uptake of E-ferries, pollutant levels around ports could fall significantly. Once enough vessels are built to provide economies of scale, this uptake could increase drastically.

3.19.5 Market drivers and readiness for technology

As stated previously this E-ferry is already in operation; although a single E-ferry has been in commercial service since August 2019, it has already received considerable publicity. Even though the ferry has been built the project is set to continue and 10 more ferries are expected to be in operation by the end of 2020. This is set to rise to 100 operating ferries by 2030; it is expected that the fleet will deliver annual savings of 10,000 to 30,000 tonnes of CO_2 in 2020, rising to 100,000 to 300,000 tonnes of CO_2 by 2030[90].

3.20 Technology 20 – Evacuation model validation data sets

Number of projects	Total value	Max Dev. Phase	Transport modes	Relevant roadmaps
3	€20,869,968	Research		CAT, VDM

The use of human data in ship-based evacuation models can help save lives. During a high stress evacuation, passengers may not be able to understand and follow instructions, while crew may be unable to communicate effectively during such a crisis. This technology is intended to provide the basis for reviewing current

[87] https://cordis.europa.eu/article/id/410195-all-aboard-fully-electric-ferry-completes-its-first-commercial-voyage
[88] https://cordis.europa.eu/project/id/636027/reporting
[89] http://e-ferryproject.eu/Home/Impact
[90] https://cordis.europa.eu/article/id/410195-all-aboard-fully-electric-ferry-completes-its-first-commercial-voyage

procedures and to build upon them to create clear guidance that will not depend on passenger skill or experience.

This technology will provide a system that can monitor the location of people on-board, provide real-time data about the situation and direct passengers and crew to the best evacuation route. It will also help to provide advanced, intuitive and easy-to-use life-saving appliances (LSA).

As well as ensuring the safety of the crowds on the ship, an IMO approved VHF (Very High Frequency) Data Exchange System (VDES) (Lázaro et al. 2019) can be integrated to inform operators on shore, resulting in quick response times to help passengers and crew after they have left the vessel.

3.20.1 Development of technology to date and current status

The SAFEGUARD (ship evacuation data and scenarios) project set out to deliver all data necessary for the calibration and validation of ship-based evacuation models, as well as to propose benchmark scenarios for certification analysis[91]. At the start of this project, there was little real-world data on people's behaviour patterns during a maritime emergency, with the IMO using an arbitrary uniform random distribution for response times that has been shown to provide inaccurate results[92].

SAFEGUARD succeeded in providing this data by running five response time data sets and two full-scale validation data sets from three different types of passenger ship including; a RoPax (roll-on/roll-off) ferry, a RoPax ferry with a significant number of cabins and a cruise ship. The only knowledge passengers had was that an assembly drill would take place at some point in the journey and to add to the realism this happened at sea, previous trials almost always occurred in ports. The study managed to obtain over 2,000 response time data points and over 3,500 passenger assembly times and passenger questionnaires[93].

After investigating this data, they found that passenger response time distributions (RTD) for RoPax and cruise ships, within public and cabin spaces, were consistent with response times in built environments; passengers respond to evacuation alarms on ships similarly to those in built environments. The project found that RTDs for RoPax ships did differ from those found in cruise ships, so different measures need to be taken depending on the type of ship.

The new RTDs are not expected to alter evacuation guidelines for RoPax ships but the study does provide a more reliable and robust RTD. In the case of cruise ships, assembly times increased for the 95th percentile by 0.1% during the day and a substantial 21.2% during the night.

SAFEGUARD also succeeded in setting new validation protocols, which involve running 50 simulations and ranking them. This project had EU funding of €2.1 million from the FP7 Transport programme, out of a total budget of €3.6 million.

The SafePASS (next generation of life saving appliances and systems for safe and swift evacuation operations on high capacity passenger ships in extreme scenarios and conditions) project is looking to produce prototypes of a system that can monitor, process and inform passenger and crew on the ship during an evacuation. They are also working with LSA manufacturers to develop easy to use LSAs. This project is still in its infancy, but once completed they hope to provide a set of recommendations to the IMO. This project has funding of €8 million from the H2020 'Smart, Green and Integrated Transport' programme.

The PALAMEON (a holistic passenger ship evacuation and rescue system) project is aiming to produce a centralised evacuation system based on mass evacuation vessels (MEV) and real-time data providing optimum evacuation strategies. This project is still very new, but they aim to produce MEV prototypes for evaluation and a smart sensor ecosystem to be tested in two different use cases. This project is funded by the H2020 programme, with a total budget of €9 million.

[91] https://cordis.europa.eu/article/id/90966-improving-maritime-emergency-response
[92] https://cordis.europa.eu/project/id/218493/reporting
[93] https://cordis.europa.eu/project/id/218493/reporting

3.20.2 Potential application of technology

One of the projects looking into this technology has already applied some of the information found to the IMO guidelines MSC Circ 1033 and 1238[94]. The other projects are also hoping that their findings can contribute to more IMO guidelines.

This technology can be used by large passenger ships but has the potential for other large vehicle evacuation plans, as the sensors and systems used to create the evacuation plan will likely be very similar, for example aircraft could use this technology to lead passengers away from a hazardous fire exit to a safer one.

This technology could also prove useful in the evacuation of large crows on the ground. Mass gathering venues could improve on their current systems to provide more optimal information to people in crowds, improving their safety.

3.20.3 Potential impact of technology

The impact of the technology could also be highly beneficial; with the ability to provide live data that can be easily understood and followed, lives can be saved. Not only are people able to escape from a potentially dangerous situation quickly, but the improvement in communication and lifesaving appliances will help the lives of those who did not manage to evade injury.

3.20.4 Alignment of technology with EU transport policy

Even though this technology does not specifically align with any environmental policies it has parallels to the 2011 White Paper goal of halving road casualties by 2020 and moving close to zero fatalities by 2050. This technology currently focuses on reducing casualties and fatalities in waterborne transport rather than road but there is some potential for the sensor and live information technology to carry down to road use.

3.20.5 Market drivers and readiness for technology

With one of the projects already having an impact on the market it seems the technology is ready to be accepted. More advancements in the technology are yet to come but with live data already being used in many industries, such as traffic alerts from mapping systems, and augmented reality being used to show hazards in ships it seems the market could readily accept this new technology. There is also a project looking at applying similar technology to evacuating large crowds[95].

3.21 Projects investigating technologies at a low development phase

Annex 1 lists the projects identified in TRIMIS that are investigating the technologies described above.

[94] https://cordis.europa.eu/project/id/218493/reporting

[95] http://www.evacuate.eu/

4 Technologies – quantitative assessment

This part of the assessment focuses on the analysis of international patent applications and scientific research to identify trends on the top 20 technologies researched at low development phases assessed in this report.

4.1 Patent development

For the analysis, the 2019 autumn EPO Worldwide Patent Statistical Database (PATSTAT[96]) dataset has been used. The dataset has been created by identifying cooperative patent classification (CPC) codes that are relevant to TRIMIS. The TRIMIS dataset includes granted patents and has the following relevant attributes: patent application number, CPC code, patent title and patent abstract.

The following steps describe the methodology carried out for the NETTs patent analysis:

1. A CPC code was attributed to each of the top 20 technologies. If a technology did not directly fit within a single category, no code was assigned;
2. A set of keywords were assigned to each technology to carry out a keyword search on titles and abstracts;
3. A year for the earliest filing date is set.

The earliest filing date was chosen as from 2013 – this year was chosen since it is the earliest available starting year from the patent database. A final quality check is carried out manually to ensure that the patents retrieved are related to each technology. Patents under the same family (e.g. same or similar patent submitted to different offices worldwide) have been counted only once. Annex 2 shows the detailed search information for each of the 20 technologies.

The search yielded different numbers of patent per technology, with the lowest number of patents (26) found for “Computer simulations modelling climatic impact on Arctic marine transportation” and for “Nanomaterials for structural health monitoring” while the highest number (383) was found for “Safety (and maintenance) improvement through automated flight data analysis”.

Figures 5 through 9 show the evolution of granted patents in the period 2013-2017, according to their earliest filing year, for the top 20 technologies, based on the patent first filling year. Patent filings from 2018 and 2019 are not shown as many patents filed in those years have not yet been granted, thus the resulting numbers can be misleading.

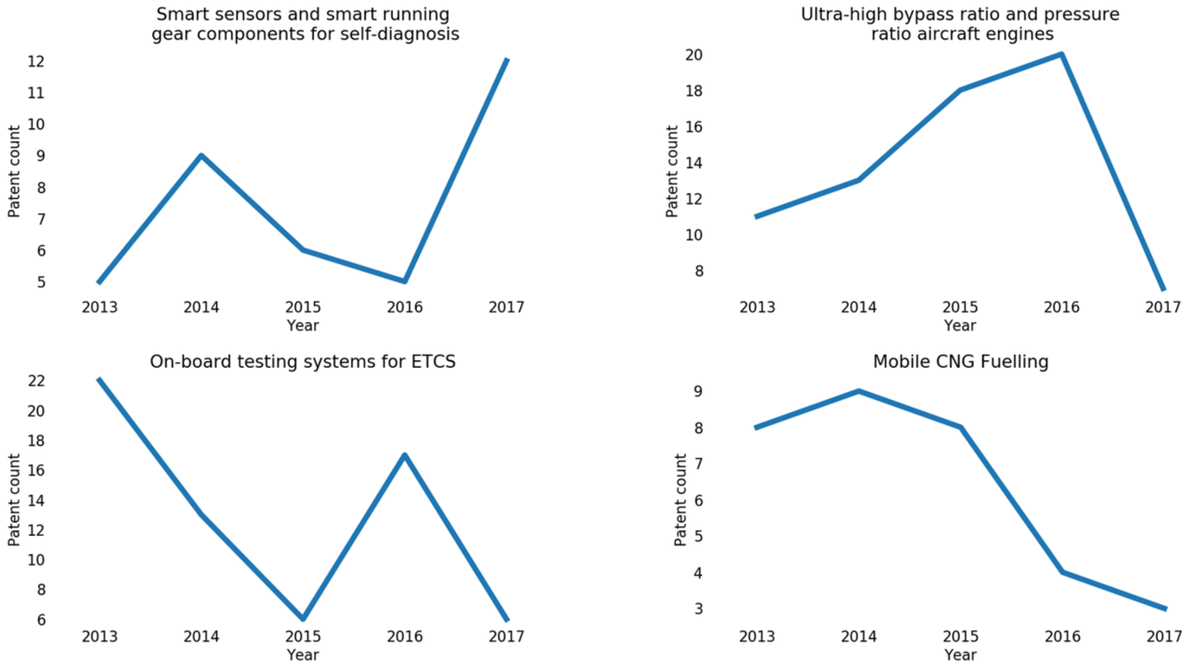
From the figures, it can be seen that there is a lot of variation in the absolute number of granted patents for each technology. This can be explained by the level of maturity of the technologies, as well as the attractiveness of filing for specific patents for each field. Moreover, the differences can also come from the various search criteria for each specific technology. Nonetheless, the technologies with the most number of patents are technologies 4 (Mobile CNG fuelling), 9 (Holistic life cycle performance assessment methods), 10 (Safety (and maintenance) improvement through automated flight data analysis) and 11 (Battery management system module), which, together with a declining patent activity, can indicate that these are the most mature technologies.

Almost all technologies have a decrease in the number of granted patents in 2017, when compared to the other years, which is understandable, as many patents filed in 2017 have not been granted yet, or are still not present in the PATSTAT database.

There are still some concerns regarding this analysis. In some cases, the technology is very recent, meaning that there are few patents granted in the database, or the patents are filed under various patent codes and data issues are common.

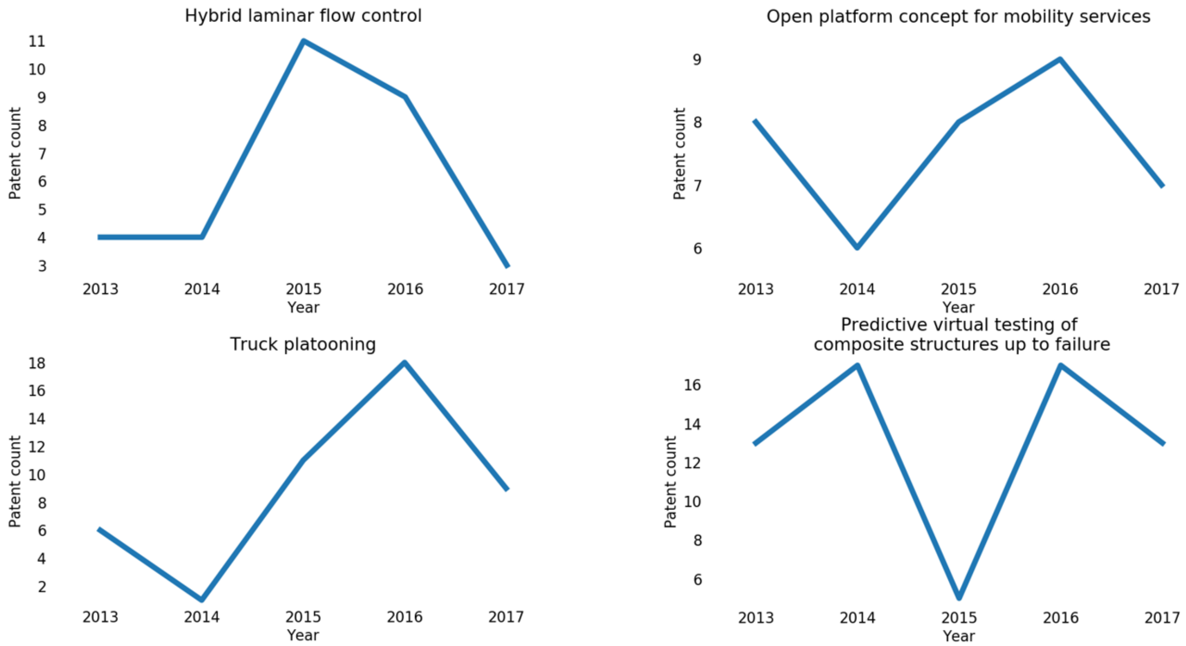
[96] https://www.epo.org/searching-for-patents/business/patstat.html

Figure 5. Evolution of granted patents between 2013 and 2017 for technologies 1 to 4



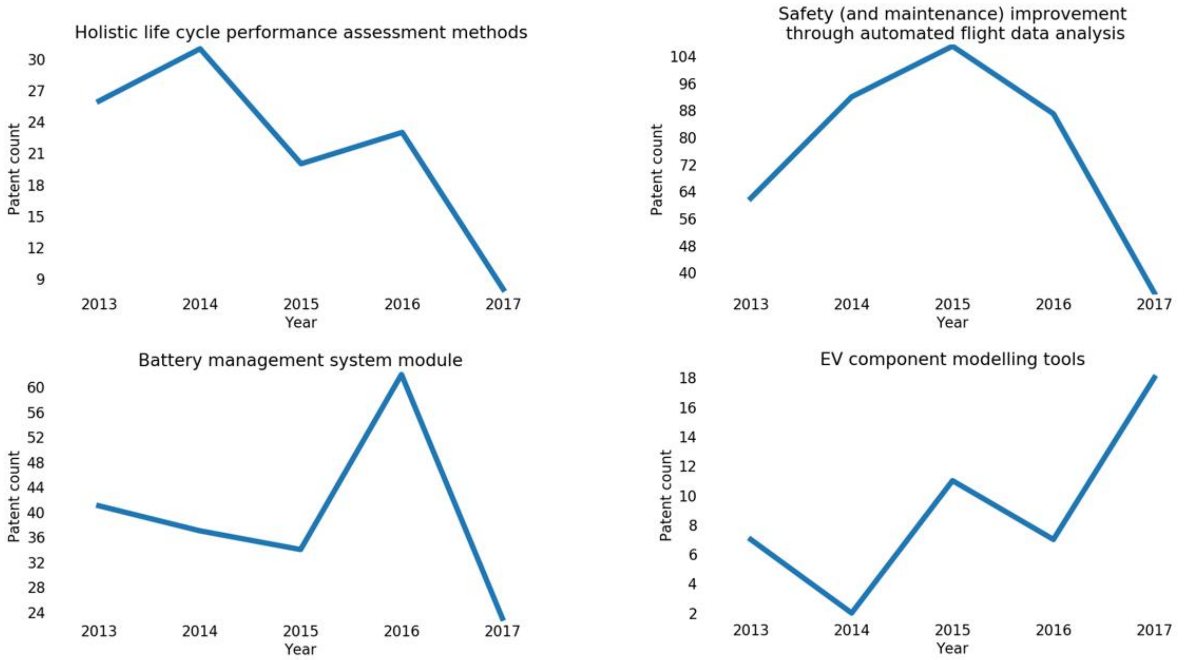
Source: TRIMIS elaborations based on PATSTAT

Figure 6. Evolution of granted patents between 2013 and 2017 for technologies 5 to 8



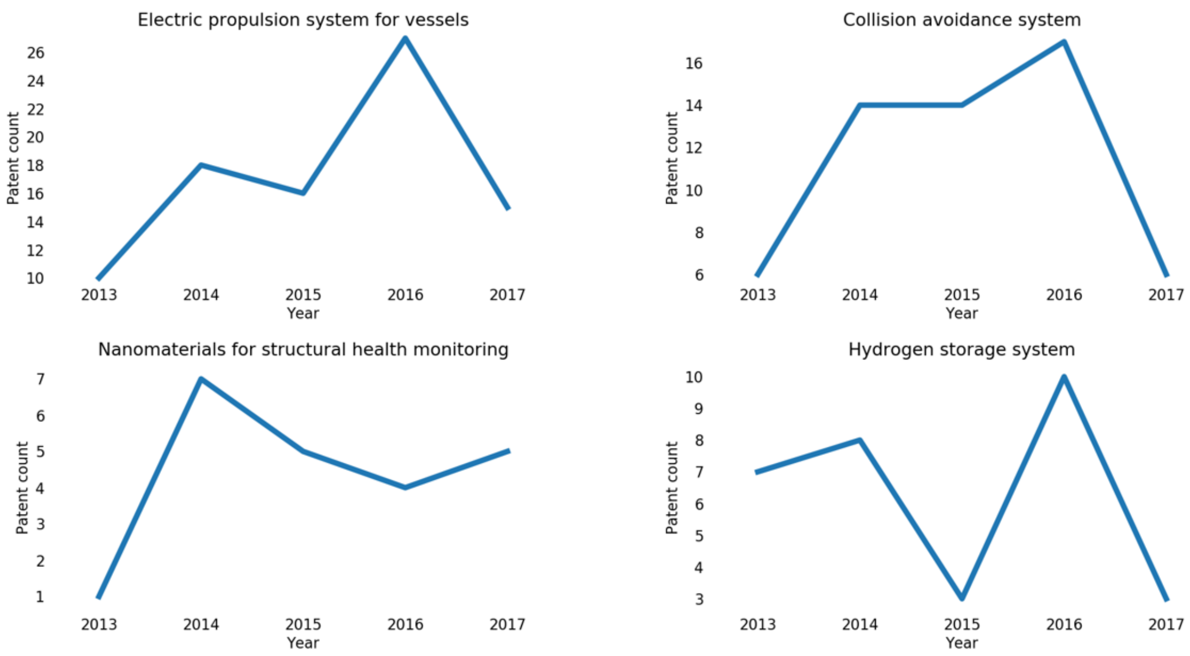
Source: TRIMIS elaborations based on PATSTAT

Figure 7. Evolution of granted patents between 2013 and 2017 for technologies 9 to 12



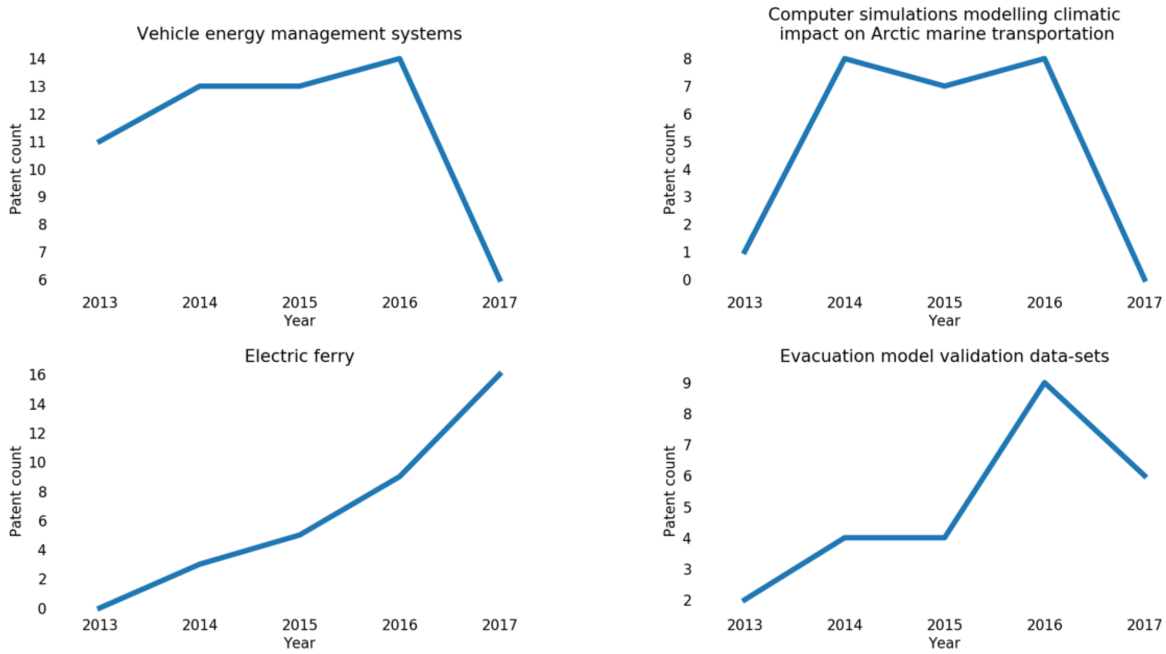
Source: TRIMIS elaborations based on PATSTAT

Figure 8. Evolution of granted patents between 2013 and 2017 for technologies 13 to 16



Source: TRIMIS elaborations based on PATSTAT

Figure 9. Evolution of granted patents between 2013 and 2017 for technologies 17 to 20



Source: TRIMIS elaborations based on PATSTAT

4.2 Trends in scientific research

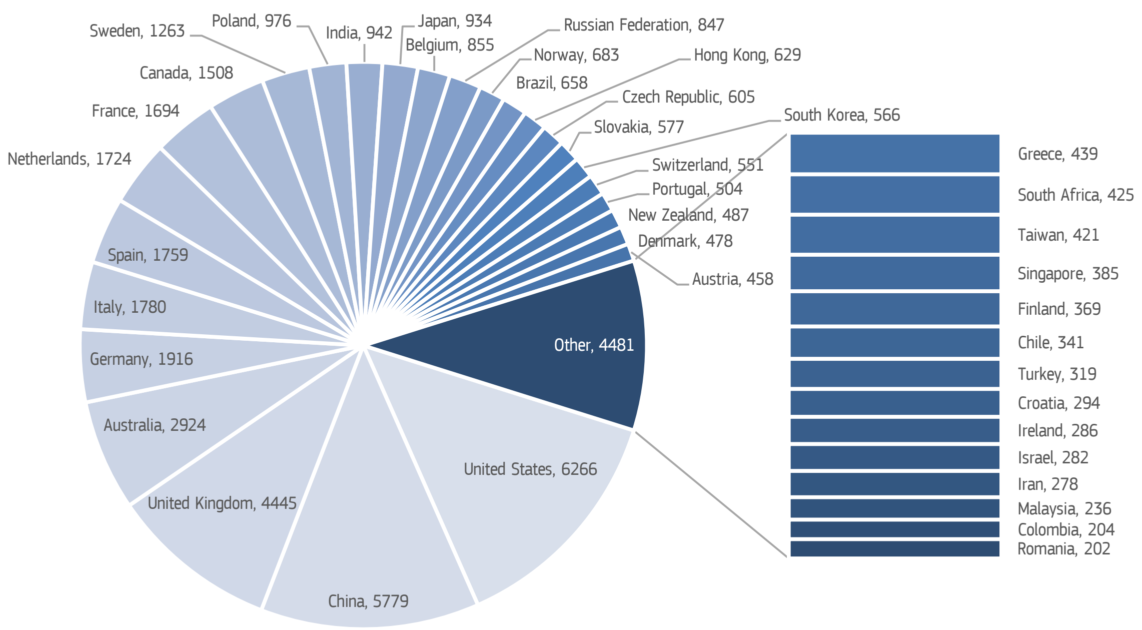
The Scopus citation database is the reference database for scientific research[97]. The following exercise has as objective to mark the evolution of peer reviewed scientific publications in the last 10 years in the areas of the top 20 identified technologies. The results provide insights on the technologies from the perspective of the Academia. Some details are necessary for the performed analyses.

- The Scopus database allows for advanced temporal, geographical and content filtering[98]. In order to have an as complete as possible coverage of the performed research, no filters other than temporal were applied.
- A number of regular expressions (REGEX) has been assigned to the 20 technologies. The REGEX derive from corroborated keywords and their synonyms. The queries built from the REGEX were applied to the title or abstract. Even though it is acknowledged that substantial amount of information is found only in the full body of text (Cohen et al. 2010; Westergaard et al. 2018) it is reasonable to believe that abstracts are adequate for this kind of exercise. The complete list of regular expression used is reported in Annex 3.
- The number of outputs per technology is linked to the query that can be more or less restrictive. Performing a comparison between technologies is not the scope of this analysis, but rather to identify trends for the specific technology.
- The queries cover the years 2010 to 2019.

Before providing the results on the technologies, it is useful to check how transport related research is mapped geographically in Scopus. Considering that there is no "transport" filter in Scopus, an effort to capture this metric is done by filtering in the "social sciences" subject area (transport is part of that) and the world "transport" in the title, abstract or keywords. This query provides good results, with the majority of source titles being in the transport sector. It is expected though that much transport related research is not captured by the query.

Figure 10 provides the results in the period 2010-2019. It includes only countries and regions with more than 200 documents. As can be observed, the United States, China and the United Kingdom are the top three countries, while five EU counties populate the top-10.

Figure 10. Overview of research in Scopus in 2010-2019 under social sciences and "transport"



Source: TRIMIS elaborations based on Scopus

[97] www.scopus.com
[98] https://www.elsevier.com/solutions/scopus/how-scopus-works/search

Table 4 provides the list of the 20 technologies. The first column reports the technology. The second column provides the keywords used (the detailed queries are reported in Annex 3). The third column provides a qualitative indication of the coverage of the query: the higher the rank the value (from one to three "+") the more specific to the technology is the coverage. The fourth column reports the number of results obtained. Finally, the last column provides the principal transport mode.

Over the next four pages the results are reported in a graphical manner. The graphs include the evolution over the period 2010-2019 (the dotted line shows the trend in the form of a 2nd order polynomial interpolation) and the top-5 countries.

Table 4. Technologies and text analysis

Technology	Query keywords	Coverage	Number of documents	Transport mode
Smart sensors and smart running gear components for self-diagnosis	diagnosis; aircraft; sensor	++	390	
Ultra-high bypass ratio and pressure ratio aircraft engines	ultra high bypass	+++	131	
On-board testing systems for ETCS	etcs	++	1332	
Mobile CNG fuelling station	refuelling; CNG	+	99	
Hybrid laminar flow control	hybrid laminar flow control	+++	52	
Open platform concept for mobility services	mobility on demand; mobility as a service	+	443	
Truck platooning	truck; vehicle; platooning	++	996	
Predictive virtual testing of composite structures up to failure	aircraft; airplane; composite structure; simulation	+	206	
Holistic life cycle performance assessment methods	life cycle assessment; vessel; maritime; boat	+	157	
Safety (and maintenance) improvement through automated flight data analysis	flight data	+	194	
Battery management system module	Vehicle; battery management system	+	4227	
EV component modelling tools	electric vehicle; component; simulation modelling	+	2263	
Electric propulsion system for vessels	ship electric propulsion	++	552	
Collision avoidance system	car collision avoidance	++	679	
Nanomaterials for structural health monitoring	damage detection; wing	+	528	
Hydrogen storage system	hydrogen storage	+	896	

Technology	Query keywords	Coverage	Number of documents	Transport mode
Vehicle energy management systems	electric vehicle; energy management	+	4051	
Computer simulations modelling climatic impact on Arctic marine transportation	arctic; marine; simulation	+	748	
Electric ferry	electric; ship; vessel; ferry	++	1353	
Evacuation model validation data-sets	evacuation model; vessel	+	63	

Transport mode icons: Air Rail Road Water Multimodal

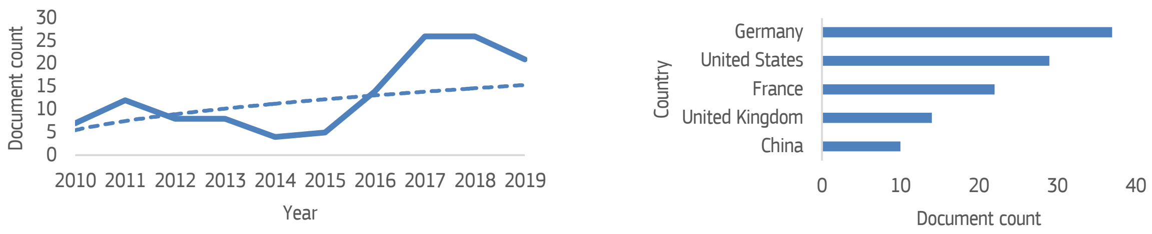
Source: TRIMIS

Figure 11 through **Figure 14** show the results of the analysis (source: TRIMIS elaborations based on Scopus).

Figure 11. Scopus research (Technologies 1-5)

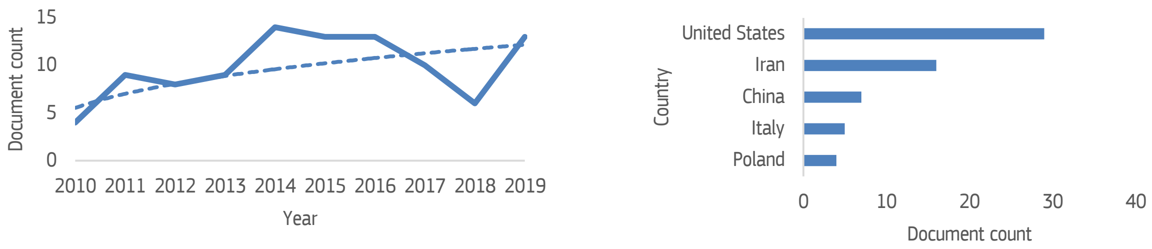
Technology 1. Smart sensors and smart running gear components for self-diagnosis

Technology 2. Ultra-high bypass ratio and pressure ratio aircraft engines



Technology 3. On-board testing systems for ETCS

Technology 4. Mobile CNG fuelling station



Technology 5. Hybrid laminar flow control

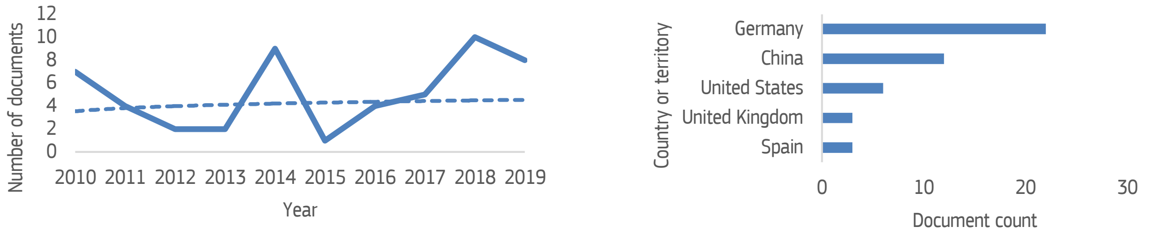
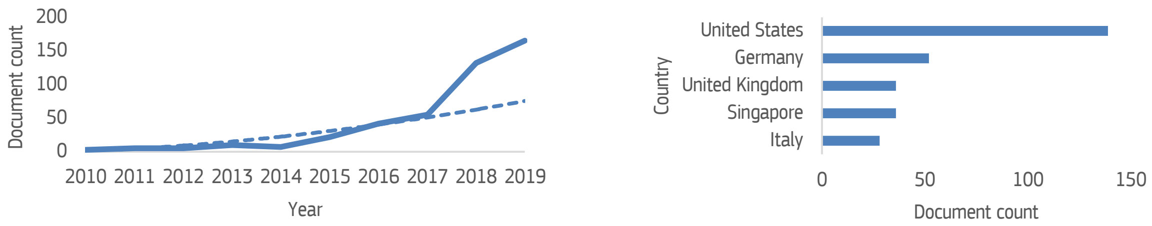
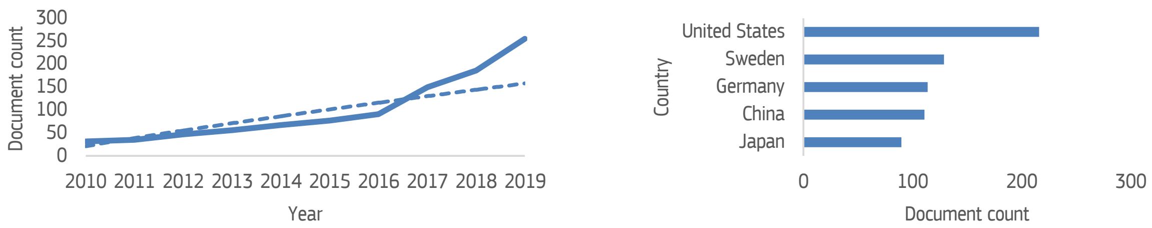


Figure 12. Scopus research (Technologies 6-10)

Technology 6. Open platform concept for mobility services

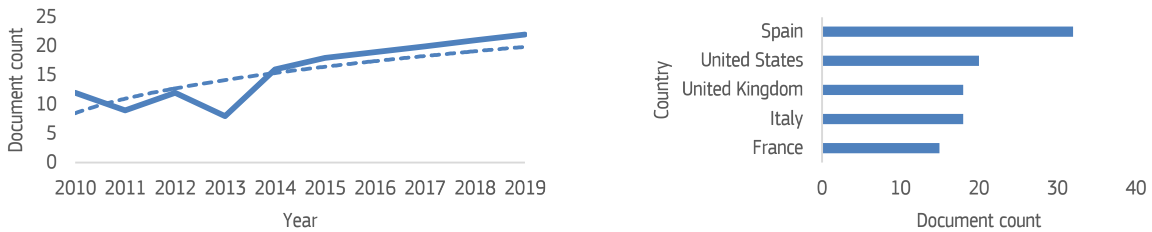


Technology 7. Truck platooning



Technology 8. Predictive virtual testing of composite structures up to failure

Technology 9. Holistic life cycle performance assessment methods



Technology 10. Safety (and maintenance) improvement through automated flight data analysis

Figure 13. Scopus research (Technologies 11-15)

Technology 11. Battery management system module

Technology 12. EV component modelling tools

Technology 13. Electric propulsion system for vessels

Technology 14. Collision avoidance system

Technology 15. Nanomaterials for structural health monitoring

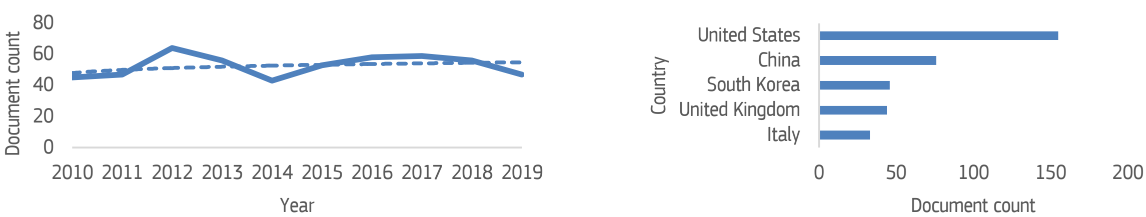
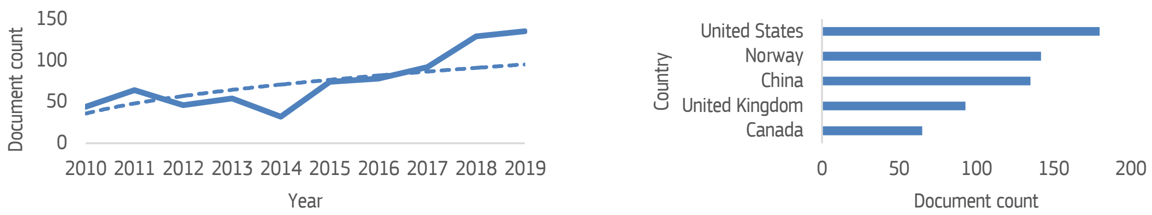


Figure 14. Scopus research (Technologies 16-20)

Technology 16. Hydrogen storage system

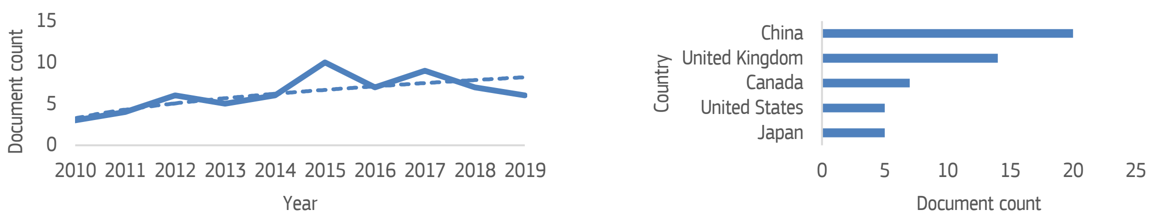
Technology 17. Vehicle energy management systems

Technology 18. Computer simulations modelling climatic impact on Arctic marine transportation



Technology 19. Electric ferry

Technology 20. Evacuation model validation data-sets



5 Overview of technologies at a high development phase

The main focus of this report is on technologies that are in the early stages of development, as they can be used to identify the direction for future research policy and funding. However, there is also interest in reviewing the technologies that have been developed to a high level of maturity (represented by having development phases of 'Demonstration/Prototyping/Pilot Production' or 'Implementation' assigned in TRIMIS), as they provide insights into the near-term developments of vehicles and transport systems. Therefore, this section provides a brief overview of the primary technologies that have been identified at a high level of maturity.

In a similar manner to that performed for low development phase technologies, and shown in Table 3, the top 20 technologies at a high development phase has been identified, based on the total value of all projects that have investigated the technology. This top 20 technologies are shown in **Table 5**.

Table 5. Top 20 technologies at a high development phase, based on the total project values

Technology	Number of projects	Value of projects	Relevant roadmaps	Relevant modes
Public charging infrastructure	45	€601,223,188	INF, ALT, SMO, ELT	
LNG refuelling station	25	€373,724,395	INF, ALT, ELT	
Hydrogen refuelling station using ionic compressor	14	€262,968,126	INF, ALT, ELT	
Hydrogen production using an electrolyser system	9	€198,033,364	INF, ELT	
Field demonstrations of sustainable urban mobility	18	€188,005,387	INF, ALT, NTM, SMO, ELT	
Biofuels for road transport	21	€184,420,916	INF, ALT, ELT, VDM	
Highly efficient aircraft engine	16	€211,209,519	ALT, VDM	
Cockpit-based technologies for improved pilot workflow	18	€198,273,421	CAT, NTM, VDM	
Collaborative logistics ecosystem	50	€143,847,727	CAT, INF, ALT, NTM, SMO, ELT, VDM	
Controllers and sensor fusion systems for automated vehicles	4	€143,345,329	CAT, SMO	
ICT support system for multimodality	74	€140,240,872	CAT, INF, ALT, NTM, SMO, ELT, VDM	
Aircraft design model	21	€137,294,775	ALT, SMO, VDM	
Air traffic management systems	13	€135,314,601	CAT, NTM, SMO	
Multimodal border management technologies	65	€126,456,741	CAT, INF, ALT, NTM, SMO, ELT, VDM	
Air Traffic Flow and Capacity Management (ATFCM) decision support tool	12	€118,505,703	CAT, INF, NTM	
Technologies to improve road safety	32	€116,103,298	CAT, INF, NTM, SMO, ELT, VDM	

Technology	Number of projects	Value of projects	Relevant roadmaps	Relevant modes
Composite materials for structural purposes in the aircraft	27	€111,628,726	INF, ELT, VDM	
Future-proof airport	20	€108,211,510	CAT, INF, NTM, SMO, ELT, VDM	
Fuel cell hybrid bus	2	€107,125,870	ELT	
Communication network for intelligent mobility	17	€97,619,760	CAT, INF, NTM, SMO, ELT, VDM	

Transport mode icons: Air Rail Road Water Multimodal

Source: TRIMIS

From the technologies listed in **Table 5**, a selection has been identified for a more in-depth review, with the aim of capturing significant technologies across the different transport modes. An effort was made to include selected technologies that cover all STRIA and all transport modes, starting from those that received the highest budget. The reviews of these technologies are presented in the following sections.

5.1 Public charging infrastructure

Technology	Number of projects	Value of projects	Relevant roadmaps	Relevant modes
Public charging infrastructure	45	€601,223,188	INF,ALT,SMO, ELT	

This technology provides a means of charging electric vehicles that is available for public use. This technology has been rolled out across Europe to adjust for the growing plug-in electric vehicle (PEV) market. Both BEVs and PHEVs can use this technology to charge the vehicle's battery.

Public charge points exist in a variety of power ratings, ranging from 'slow' chargers rated at 3 kW to 'ultra-rapid' chargers that can be up to 350 kW. The higher the power rating, the faster the vehicle's battery can be charged. Public chargers are better suited to the higher-powered rating chargers, as these can charge users' vehicles faster and hence reduce journey delay. A typical public charger could be rated at 43 kW AC or 50 kW DC, which can charge 80% of the vehicle's battery in 30 minutes, depending on the battery's storage capacity. Different vehicles can accept different power ratings and current type (AC/DC), depending on model and manufacturer.

The high-powered chargers under development, at 350 kW, have the potential to charge a large EV battery (75-100 kWh range) up to 80% in just 10 to 15 minutes[99]. This technology will greatly reduce the time waiting for the battery to charge, which is often cited as a reason for a customer not selecting an electric vehicle over a conventionally fuelled vehicle. However, not many vehicles can currently accept the 350 kW power rating.

5.1.1 Development of technology and benefits

In 2019, there were 164,024 standard public charge point (less than 22 kW) and 20,171 fast public charge points (over 22 kW) across Europe[100]. In 2018, there were 122,178 standard and 14,377 fast chargers across Europe. This represents an increase of around 35% in the total number of public charge points from 2018 to 2019 alone. This technology has seen significant developments over the last 10 years. In 2011 there were just 3,882 standard public charge points across Europe, and no fast chargers at all.

[99] https://electrek.co/2018/12/06/electrify-america-first-350kw-charger-california/
[100] https://www.eafo.eu/electric-vehicle-charging-infrastructure

There has been significant EU investment into this technology; including 45 different projects with a total value of €601,223,188. There has been a total of 69 organisations involved in public charging infrastructure. The global electric vehicle market is predicted to be worth $802.81 billion by 2027[101], and public charging infrastructure is needed to help facilitate the uptake of these vehicles.

Of the 45 projects, 30 of them have been directly funded through the CEF for Transport. Many of the projects are currently on-going and are focused on the roll-out of public charging infrastructure. Within the project URBAN-E there is a pilot deployment of 167 charging points to be fully integrated in municipal transport strategies within three European cities (Bratislava, Zagreb and Ljubljana). The project partners from AMBRA-Electrify Europe have an ambitious target to deploy 3,169 electric vehicle charging stations on six TEN-T core network corridors; these can be paid for on an ad-hoc basis by the public.

The more recent projects funded under CEF are focused on creating a network of ultra-rapid charge points (over 100 kW power rating) across Europe. The project MEGA-E has a target for the deployment of 202 ultra-rapid chargers (350 kW) in 30 greater-metropolitan areas within 13 countries along the core network corridors. IONITY is a joint venture of BMW Group, Daimler AG, Ford Motor Company, VW Group, Audi and Porsche, which also receives funding from the CEF Transport programme. In January 2020, IONITY ordered 324 chargers rated at 350 kW to be rolled out in 24 countries by the end of 2020[102]. This private venture complements the EU-funded projects rolling out ultra-high-powered electric vehicle chargers[103],[104].

5.1.2 Future technology requirements

The Alternative Fuels Infrastructure Directive requires the introduction of a minimum level of infrastructure for charging electric vehicles across the EU at one public charging point for every ten electric vehicles[105]. It has been predicted that to meet the EU's climate neutral targets, almost 3 million charge points will be required across Europe by 2030[106]. This represents a large increase over the current number of public chargers (around 185,000 standard and fast) and hence will require significant funding from both private and public entities to reach the EU targets.

5.2 Hydrogen production and refuelling

Technology	Number of projects	Value of projects	Relevant roadmaps	Relevant modes
Hydrogen refuelling station using ionic compressor	14	€262,968,126	INF,ALT,ELT	 
Hydrogen production using an electrolyser system	9	€198,033,364	INF,ELT	 

The two TRIMIS technologies, 'Hydrogen refuelling station using ionic compressor' and 'Hydrogen production using an electrolyser system' have been combined in this section to represent a more general range of technologies under the topic of hydrogen production and refuelling.

Hydrogen can be used as a transport fuel, either in a gaseous form directly in an ICE, or more commonly to generate electrical power through a fuel cell. This fuel can be utilised across multiple transport modes. Hydrogen as a transport fuel has many challenges, including the optimal storage of the hydrogen as discussed in paragraph 3.163.16 above. Technologies concerning hydrogen as a transport fuel which have a higher development phase (i.e. more mature technologies) include the production of hydrogen using an electrolyser system and the refuelling of hydrogen by use of an ionic compressor.

[101] https://www.alliedmarketresearch.com/electric-vehicle-market
[102] https://www.greencarcongress.com/2020/01/20200110-abb.html
[103] https://europ-e.eu/
[104] https://www.ultra-e.eu/
[105] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0094&from=EN
[106] https://www.transportenvironment.org/publications/recharge-eu-how-many-charge-points-will-eu-countries-need-2030

5.2.1 Development of technology and benefits

Hydrogen can be produced using electrolysis; splitting water and producing hydrogen onsite. This requires considerable amounts of electricity, but not transport of the fuel. If this electricity is from renewable sources, then the hydrogen will be identified as green hydrogen. If the electricity is supplied from the grid, then this would be identified as brown hydrogen, unless the grid energy was 100% renewable. It should be noted that with all hydrogen production there is a loss of efficiency due to the conversion of electricity to hydrogen – this results in approximately a 30% loss of energy[107]. Due to the potential for the hydrogen to be produced through renewable electricity, and hence become a carbon neutral fuel, there is high levels of interest in the electrolysis technology.

An often discussed drawback of pure-battery electric vehicles is the currently available recharging time, particularly for the larger battery vehicles and HGVs. A benefit of hydrogen is the ability to achieve similar refuelling times to conventional fossil fuelled vehicles. Ionic compressors allow for the hydrogen to be dispensed at greater pressure than traditional methods, thus further reducing the overall refuelling time. Traditional hydrogen refuelling methods consist of a mechanical piston; whereas an ionic compressor consists of a column of ionic liquid in direct contact with the gaseous hydrogen which can condense the hydrogen up to a pressure of 100 MPa[108].

The Hydrogen Mobility Europe project (H2ME) has a total project value of around €62 million (€32 million EU contribution) and is focused on a large-scale rollout of hydrogen vehicles and refuelling infrastructure. A specific target of the project is to deploy 29 state-of-the-art hydrogen refuelling stations using the most up to date technology. Due to the scale of the deployment the costs will be lower than in other hydrogen refuelling infrastructure. The project partners from COSMHYC XL aim to develop an innovative compression solution for extra-large hydrogen refuelling stations, based on the combination of a metal hydride compressor and a diaphragm compressor. A prototype will be developed at a scale of 1/10 the real size and will be tested under real conditions for six months.

There are currently 130 hydrogen refuelling stations across Europe; with 47 more under development[109]. A number of hydrogen refuelling stations are now in operation using an ionic compressor, which are achieving a fuelling pressure of up to 70 MPa and a hydrogen throughput of 30 kg per hour[110]. A fuel tank of around 5 kg of hydrogen can provide a driving range of approximately 350 miles[111], meaning that a total of 2,100 miles of overall driving range can be refuelled per hour by a hydrogen refuelling station using an ionic compressor.

5.2.2 Future technology requirements

A hydrogen roadmap for Europe predicts that hydrogen could account for 24% of the final energy demand across all sectors within Europe[112]. This is a substantial demand for hydrogen as a fuel; meaning that the mass scale-up of hydrogen produced from electrolysis is necessary to meet the demand. Currently only around 4% of all hydrogen is produced using electrolysis worldwide (Shiva Kumar and Himabindu, 2019), with the remainder produced from fossil fuels. If the European Green Deal decarbonisation targets are to be met, then the amount of hydrogen produced from electrolysis will have to increase greatly.

[107] https://cleantechnica.com/2018/08/11/hydrogen-fuel-cell-battery-electric-vehicles-technology-rundown/
[108] https://www.linde-engineering.com/en/plant_components/hydrogen-fueling-technologies/index.html
[109] https://h2.live/en
[110] https://www.linde-engineering.com/en/images/Reference%20data%20sheets_international_tcm19-523710.pdf
[111] https://www.smmt.co.uk/wp-content/uploads/sites/2/2019.03.11-SMMT-FCEV-guide-FINAL.pdf
[112] https://www.hydrogeneurope.eu/news/hydrogen-roadmap-europe-has-been-published

5.3 Cockpit-based technologies for improved pilot workflow

Technology	Number of projects	Value of projects	Relevant roadmaps	Relevant modes
Cockpit-based technologies for improved pilot workflow	18	€198,273,421	CAT,NTM,VDM	

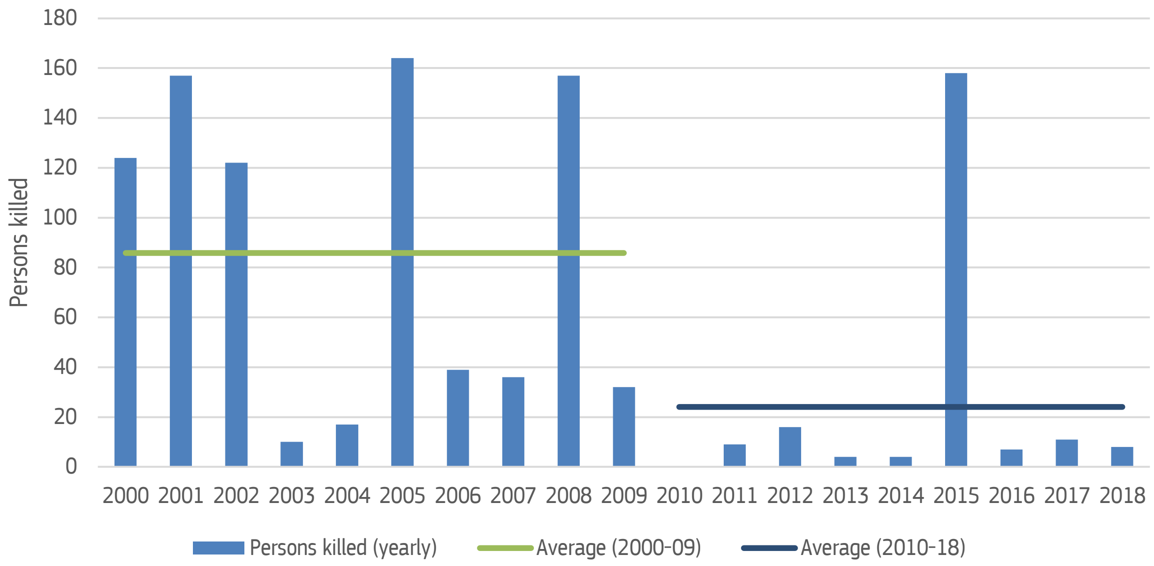
Cockpit-based technologies for improved pilot workflow are a group of technologies which aim to reduce pilots' peak workload and support them in dealing with difficult situations, thus enhancing safety and performance. This can include hardware and software implementation of smart sensors to monitor cognitive states such as drowsiness and fatigue, which will allow for an increase in flight safety.

Specific technologies have included a vision-based system integrated in the cockpit dashboard to continuously monitor the pilots in the cockpit and detect behaviour linked to drowsiness, and a smart wristband which will sense several bio signals through advanced optical sensing technologies before, during and after the flight. There are also automation systems to support the flight crew during intense workloads, reducing the overall stress on the crew. Technologies exist which enable a reduced crew to operate safely in certain conditions; involving different scenarios such as intentional reduction of crew during long-haul flights, partial crew incapacitation and even full crew incapacitation. This can be particularly useful in rare instances where the pilot suffers from physical or psychological issues.

5.3.1 Development of technology and benefits

In 2008 the worldwide accident rate per million departures was 4.7 for commercial flights above 5.7 tonnes. In 2019, this accident rate was 2.7 per million departures[113]. This reduction is due to a number of factors, although it can be partially attributed to reduced pilot stress and improved cockpit technologies. **Figure 15** below shows the total number of persons killed in commercial air transport in the EU-28 from the year 2000 to 2018. The average persons killed from the period 2000-09 was 86, whereas the period 2010-18 had 24 persons killed on average per year. Although this is a reduction on average, it is clear that work still needs to be done to reach zero fatalities in commercial air transport.

Figure 15. Persons killed in commercial air transport in the EU-28[114]



Source: Own elaborations based on Eurostat

[113] https://www.icao.int/safety/iStars/Pages/Accident-Statistics.aspx
[114] https://ec.europa.eu/eurostat/statistics-explained/index.php/Air_safety_statistics_in_the_EU

Pilot error is the largest contributor to fatal accidents worldwide (57% in the period 2010 to present[115]), and hence the cockpit-based technologies to improve pilot workflow can have a considerable impact on overall flight safety and reduce fatalities in commercial air transport.

The project partners from the HIPNOSIS project will demonstrate two systems to automatically detect suspicious pilot behaviour before, during and after the flight. These systems will be deployed in a Dassault Falcon 7X cockpit. A demonstrator is also proposed within the AS-DISCO project. This demonstrator will include a human-machine interface (HMI) which aims to reduce crew workload, improve pilot situational awareness and support disruptive and innovative cockpit operations.

In September 2019, Airbus announced in-flight trials of connected cabin technologies[116], becoming the first aircraft manufacturer to undertake flight-testing of actual connected cabin innovations. Aircraft crews will potentially have a better working environment with access to more efficient tools digitally enabled by real-time data from an IoT platform throughout the cabin. A mobile smart device will also allow crews to monitor and operate all components.

A new instructive tool HuMans (Thales Group)[117] equips the simulator cockpit (used for training pilots) with cameras and sensors that can measure and assess the pilot's behaviour, attitude and stress levels. The sensors can track eye movement; immediately alerting the instructor to inappropriate behaviour. This allows the instructor to more effectively train pilots in real-world conditions and could even be applied to commercial flights by alerting co-pilots to high stress levels of colleagues.

5.3.2 Future technology requirements

With an average of 24 yearly fatalities in commercial flights across the period 2010-2018, there is still a real need for advances in cockpit-based technologies for improved pilot workflow. The more recent ongoing projects are researching technologies such as using machine learning for operational factors such as task responsibilities and situational awareness. There is a future aim to have improved human-machine information sharing mechanisms during commercial flights, which will help to provide more automation and reduce pilot's workload and stress above the current technology capabilities.

5.4 ICT support system for multimodality

Technology	Number of projects	Value of projects	Relevant roadmaps	Relevant modes
ICT support system for multimodality	74	€140,240,872	CAT,INF,ALT, NTM,SMO,ELT, VDM	

ICT support systems are used to bring multiple benefits to public organisations by providing real-time visibility, efficient data exchange and better flexibility to react to unexpected changes along the route. Recent developments in the field of ICT such as cloud computing, social networking and wireless communication have further developed the ways information is shared and supply chains are structured.

ICT support systems for multimodality have a particular benefit to freight and logistics. Freight is often moved via various transport modes; including long-haul shipping, medium haul rail and then last mile by road. Given the multiple modes of transport and interchange of goods there are often inefficiencies and delays. ICT systems can synchronise vehicle movements and logistics operations across various modes to adapt to changing conditions. This is achieved through dynamic planning methods involving intelligent cargo, vehicle and infrastructure systems, along with resources and information from different stakeholders, hence creating an open freight management eco-system.

5.4.1 Development of technology and benefits

In the UK in 2019, 4.7% of freight train journeys arrived at their destination 15 minutes or more over their scheduled arrival time[118]. In 2015, a worldwide statistic found that the overall punctuality for containerships

[115] http://www.planecrashinfo.com/cause.htm
[116] https://www.airbus.com/newsroom/press-releases/en/2019/09/airbus-commences-inflight-trials-of-connected-cabin-technologies.html
[117] https://www.thalesgroup.com/en/worldwide/aerospace/magazine/taking-guesswork-out-evaluating-pilots
[118] https://dataportal.orr.gov.uk/media/1487/freight-rail-usage-performance-2019-20-q1.pdf

only reached an on-time performance of 73%[119]. These delays all add up in terms of additional fuel consumption and hence increased CO_2 emissions, increased air pollutants and increased costs for operators and end-users. Increased efficiency in logistics operations from utilising an ICT support system leads to lower emissions (CO_2 and pollutant) as well as being more financially and socially sustainable in the long term. This is particularly the case when multimodal logistics and transport are considered, as delays in the first mode of transport have a knock-on effect and cause further delays along the supply chain.

The project GOEASY is focused on the application of cloud-based ICT platforms to enable a new generation of location-based services to support commercial transport services. The project will develop two systems, ApesMobility and the AsthmaWatch, both of which will be evaluated by engaging real users in a medium-scale pilot in Torino (Italy) and Stockholm (Sweden). A CEF Action (Pilot implementation of an Upper Rhine traffic management platform), included a pilot deployment of an ICT traffic management system in nine inland ports across Europe. The Action led to higher efficiency in the inland waterway logistic processes as well as to lower CO_2 emissions by reducing waiting times for ships and better capacity utilisation. There was also a design for the extension of the ICT platform to non-containerised cargo included rail and road; hence creating a multimodal ICT platform.

NxtPort have released a service called Logit One[120] which provides insights into global end-to-end shipment for logistics operators. It consults multiple data sources and automatically feeds data and information back into the operational systems or customer portal. This is an example of how an ICT support system for multimodality has been developed in practice and is used by operators. The use of the NxtPort technology has been regarded as a success in the Port of Antwerp use-case. Key stakeholders have used the data platform and have seen reductions in redundant data entry and data inaccuracy. Cost savings and operational performance improvements have followed.

5.4.2 Future technology requirements

Future developments in this technology are focused on using big data and the IoT to develop machine-learning models to predict freight movements and improve multimodal operations. Traxens, a company providing high-value data and services for the supply chain industry, announced in 2019 a new solution which provides comprehensive, precise and timely data about cargo by tracking wagons and smart containers in transit anywhere in the world. This is achieved through the use of dedicated sensors, an IoT network and a customised portal[121]. Similarly, NxtPort have future plans to improve the data platform offered by utilising blockchain data records and the IoT.

The use of an IoT network could provide much more accurate real-time data, allowing for multimodal logistics operators to optimise the supply chain and reduce overall delays in the transportation of goods.

[119] https://www.sciencedirect.com/science/article/pii/S2092521217300251
[120] https://www.nxtport.com/market/applications/logit-one
[121] https://www.businesswire.com/news/home/20190602005024/en/Traxens-Showcase-Multimodal-Offering-Transport-Logistic-Exhibition

6 Conclusions

Focusing on EU-funded projects, this report presents a comprehensive analysis of 20 promising transport technologies at their early stage of development in Europe in the last years. The report critically addresses the development of the technologies to date, their potential applications and impact, as well as their alignment with European policies. The analyses are integrated with findings from the Scopus research database and the TRIMIS patent database that highlight research and worldwide trends in the private sector. The report highlights also possible technology spill overs of the assessed technologies across transport modes.

From the assessment carried out, the description and potential of these technologies are reported below, separated by transport modes, while the potential alignment of the technologies with EU transport policies is aggregated by transport mode.

On aviation:

1. **Smart sensors and smart running gear components for self-diagnosis** are sensors that include an internal circuit capable of showing if the reading is likely to be true or whether there may be a malfunction with the sensor. When incorporated into an aircraft, they can also be used to remotely identify mechanical issues, which can then be transmitted to the mechanics on the ground. The introduction of smart sensors in aircraft structures could contribute to improving overall flight efficiency. Flight safety should also increase as sensor failures have resulted in disastrous consequences in the past. These sensors can be applied also to trains.
2. A high bypass engine is an engine that produces significantly more fan thrust, with an ultra-high bypass ratio engine have a bypass ratio greater than 12. The **ultra-high bypass ratio and pressure ratio aircraft engine** technology is expected to be required to allow future aircraft types to achieve the targeted reductions in noise, CO_2 and NO_x emissions. Using ultra high bypass ratio engines in aircraft can provide substantial improves in fuel consumption, with estimates showing a reduction in fuel burn of 50%.
3. **Hybrid laminar flow control** (HLFC) provides a way to reduce drag on an aircraft in flight by reducing the regions of turbulent flow, thus improving aircraft efficiency and reducing fuel consumption. By reducing turbulent flow around the aircraft wings, the aircraft can fly with reduced drag and increased stability. Once properly tested and standardised, this technology could be applied to any size of aircraft, and all key aircraft structures such as the wings and tail.
4. The **predictive virtual testing of composite structures up to failure** technology uses simulation-based design to provide a quicker and cheaper route to the production of composite aircraft structures, such as the fuselage. The whole aircraft industry could benefit from this technology as it is applicable to composite aircraft structures that are now in widespread use. If successful this technology will result in significant reductions in time, as much as 50% in the assembly time of the fuselage. It can also help reduce recurring manufacturing and assembly costs by 10% and reduce the weight of the aircraft by 10%.
5. **Safety (and maintenance) improvement through automated flight data analysis** is targeted at enhancing flight operational safety and smart maintenance using intelligent and automated flight data monitoring. A standardised, automated flight data management system, capable of processing large quantities of data, could be used by operators to improve the analysis of all available flight data. This can be made easier using a common methodology of flight data analysis, based on singular points of automation. Analyses from different aircraft types and operators would then be comparable and easily combined. In principle, this technology could be implemented immediately as the only requirement is access to sufficient flight data. It can apply to all areas of aviation concerning safety, commercial and private, large and small aircraft, military and civilian.
6. A **collision avoidance system** is a tool used to improve the safety of vehicles by either preventing or reducing the severity of a collision; this can range from a warning signal to the driver of a potential collision to an automated avoidance of the collision without the need for driver input. Sensors can also be used by aircraft, not only for detecting other aircraft to avoid collisions, but also providing visual information for pilots in adverse weather conditions to safely take off and land aircraft.
7. **Nanomaterials for structural health monitoring** uses damage detection systems, often built inside the structure, capable of relaying information to a user who can identify any damage and

assess its severity. This damage can be a physical change in the geometry of the structure, or internal to the materials from which the structure is constructed. Nanomaterials have beneficial properties compared to their counterparts, such as increased strength to weight ratio or higher levels of electrical conductivity. This technology can bring benefits to the aircraft industry, but also other types of vehicles and moving machine parts used in manufacturing industries or other machinery with fluid control systems. The electrical properties of carbon nanotubes can be used in many other industries too, with the potential to generate and transmit data from one single structure.

Smart sensors and smart running gear components for self-diagnosis can contribute to the achievement of the 2011 White Paper goal of a modernised air traffic management infrastructure with a much more efficient air traffic management. The increased fuel efficiency of **ultra-high bypass ratio and pressure ratio aircraft engines** and the weight reductions using **predictive virtual testing of composite structures up to failure** and of **nanomaterials for structural health monitoring** will contribute to meeting the EU targets of a 50% reduction in transport emissions by 2050 and improvements in air quality around airports. With a greatly increased efficiency from reduced drag on the aircraft structure in flight and therefore reduced fuel consumption, **hybrid laminar flow control** can help reach the targets of 40% low-carbon sustainable fuels in aviation of the 2011 White Paper and the European Green Deal's aim of 90% reduction in transport emissions by 2050. **Safety (and maintenance) improvement through automated flight data analysis** and **collision avoidance system** can also improve the safety of aircraft, a key goal in the Single European Sky (SES) initiative which looks at improving safety by a factor of 10.

On rail transport:

8. The European Train Control System (ETCS) is the signalling and control component of the European Rail Traffic Management System (ERTMS), the system of standards for management and interoperation of signalling for railways by the EU. ETCS is a system designed to calculate the safe maximum speed for each train, which happens continuously throughout the journey. The **on-board testing systems for ETCS** technology has the potential to remove the need for trackside signalling by incorporating radio-based data transfer that can monitor the spacing between trains along the railway network.

ETCS capacity improvements will benefit the rail freight sector and will contribute to the European Green Deal policy of freight modal shift from road to rail.

On road transport:

9. A compressed natural gas (CNG) fuelling station is a system to refuel vehicles that run on CNG. The **mobile CNG fuelling station** technology can be placed along existing gas pipelines, subject to constraints due to varying pressures. Mobile fuelling stations are designed to be distributed into key locations where natural gas pipelines cannot reach. This allows the CNG network to be extended and give additional coverage. This technology will help towards the ramp up and deployment of sustainable alternative transport fuels. However, to gain the full benefits of using CNG as a fuel, from the extraction to the powering of vehicles, research will need to be conducted into production methods that include carbon-neutral natural gas (or methane).
10. The **open platform concept for mobility services** technology relates to an integrated open data mobility platform, which gathers information from all transport modes and provides information to the user. The platform can include multimodal travel options and will provide a consolidated database of mobility services in real time. This will allow the user to enter a desired origin and destination; with a range of real-time journey options provided. The main aim of this technology is to make travelling using a range of modes easier by facilitating the use of the mode, or modes, that are most appropriate for a particular journey. This in turn will bring the benefits from increased public transport use and decreased personal-car use.
11. **Truck platooning** is an area of research that falls under cooperative, connected and automated transport, specifically regarding heavy goods vehicles (HGVs) along motorways. A platoon is a group of vehicles (HGVs in this case) that follow closely behind one another. The vehicle at the front of the platoon controls the speed, acceleration and braking; the other vehicles in the platoon are wirelessly connected to the lead vehicle and automatically copy its driving behaviours. There have been developments in general truck platooning, with trials undertaken throughout Europe. Multi-brand tuck platooning will, in theory, allow for any HGV to join and leave a platoon irrespective of the vehicle manufacturer. This technology will be implemented via on-board units in vehicles, which will allow for

wireless communication between the vehicles. Truck platooning technology can help to reduce traffic collisions and improve overall highway safety. It also aligns with the EU policy to develop smart systems for traffic management, which will improve transport cooperativity and connectivity.

12. **Battery management system (BMS) modules** are electronic devices that allow for the monitoring of the state-of-charge (SOC), temperature (to prevent overheating) and control over individual cells within the battery pack of battery-electric vehicles (BEVs). This technology will just be added into the vehicles at the manufacturing stage, with the end-user able to see the benefits immediately. This technology can effectively monitor and manage battery health, resulting in a potential longer lifetime of a battery.
13. **Electric vehicle component modelling tools** are technologies that allow for the integration of virtual and real-world testing for all types of electric vehicles and their components in the design phase. This technology can consist of complex and accurate simulations of various EV components, allowing for virtual testing to replace real-world testing in some cases. This will potentially remove the need for real-life testing of certain systems.
14. Hydrogen used as a transport fuel is seen as a potential way to decarbonise all forms of transport. Hydrogen can be produced via an electrolysis process. To improve the energy volume density, advanced hydrogen storage methods are required. The **hydrogen storage system** technology would be directly implemented into vehicles and refuelling stations. It would allow for improved hydrogen vehicle safety and driving range, as well as increased capacity for the hydrogen refuelling stations.
15. As BEVs do not have internal combustion engines (ICEs), there is no residual heat to use for cabin heating in cold weather. This means that the energy for climate control comes directly from the battery in cold weather (heating) as well as in hot weather (cooling/air conditioning). **Vehicle energy management systems** are implemented to effectively manage and maximise the driving range of the BEV, considering that batteries for electric vehicles have limited energy storage.

The introduction of **mobile CNG fuelling stations** will help to achieve greater CNG distribution, in line with the requirements of the alternative fuels infrastructure directive for availability of an appropriate number of CNG refuelling points in urban/suburban and other densely populated areas along the TEN-T core network by 2025, and will help towards the ramp up and deployment of sustainable alternative transport fuels, thus contributing towards meeting the goal included in the European Green Deal. **Open platform concept for mobility services** has the ability to support sustainable urban mobility plans (SUMPs), which are in-line with EU policy on improving air quality, reducing congestion and reducing CO_2 emissions from transport. The efficiency delivered by **truck platooning** aligns with the EU policy to develop smart systems for traffic management, which will improve transport cooperativity and connectivity and with the Europe on the Move policy, which aims to have automated driving on motorways (in particular truck platooning) within the 2020s, moving towards full autonomous mobility in the 2030s. **Battery management system (BMS) modules** could increase the attractiveness of new and older BEVs; helping to remove conventionally fuelled vehicles from the road, and help achieve CO_2 reduction targets for new cars and vans in line with the performance standards for cars and vans post-2020 policy, due to the zero CO_2 tailpipe emissions from BEVs. **EV component modelling tools** could allow for an improved time-to-market for electric vehicles, and hence accelerate their market uptake in Europe. This will help towards the policy goal of reducing 'conventionally-fuelled' cars in urban transport and provide a route for road transport decarbonisation. **Hydrogen storage systems** will help with the attractiveness of hydrogen powered vehicles in all transport modes and help to achieve cleaner air, particularly in urban areas. **Vehicle energy management systems** can increase the attractiveness of electric vehicles by offering a higher real-world driving range when using climate control; the subsequent increased use of electric vehicles will help to reduce the amount of air pollution in urban areas.

On waterborne transport:

16. **Holistic life cycle performance assessment methods** would involve looking at the emissions during each section of a vehicle's life, from the mining of raw materials used to build the vehicle up until the eventual breakdown of the vehicle and what happens to those products, whether they are recycled, discarded or reused. This technology can be implemented in several different ways. Research to date has focused on application to ships, but holistic LCA can be applied to almost any industry. With current goals to drastically reduce emissions every technological sector could look at its emissions across its whole lifetime, rather than just the running emissions.

17. An **electric propulsion system for vessels** uses electrical energy to power the propeller of a boat; this can be from a small fishing boat all the way up to a commercial ferry or cruise ship. This technology can be implemented in numerous ways, for immediate effect the propellers can be fitted into sailing ships already in service; in the long-term new ships can be built with these propellers already fitted.
18. **Computer simulations modelling climatic impact on Arctic marine transportation** will use computer simulations to model the impact of climate change on Arctic marine transportation. Arctic climate predictions are quite accurate when looking at the short term (yearly) and much longer term (several decades), but they are much poorer when looking at the intermediate scale. The evolution of the Arctic climate will have a critical influence on its marine ecosystems and human activities; This technology can be used by parties involved in business around the Arctic to gain a clearer understanding of the future and make informed plans taking account of the effects of climate change
19. **Electric ferry** looks at demonstrating the viability of a 100% electrically powered, emission free ferry. The ferry will be medium-sized and capable of carrying passengers, cars, trucks and cargo around island communities, coastal zones and inland waterways. The innovative vessel will look at covering distances much larger than the current electric drivetrain ferries, which can handle just under 5 nautical miles between charges. With a range of 22 nautical miles between journeys, this technology can be applied to many ferry routes currently in operation, with pilot implementation in Denmark already happening.
20. The **evacuation model validation data sets** technology will provide a system that can monitor the location of people on-board, provide real-time data about the situation and direct passengers and crew to the best evacuation route. It will also help to provide advanced, intuitive and easy-to-use life-saving appliances (LSA). This technology can be used by large passenger ships but has the potential for other large vehicle evacuation plans, as the sensors and systems used to create the evacuation plan will likely be very similar, for example aircraft could use this technology to lead passengers away from a hazardous fire exit to a safer one.

Holistic life cycle performance assessment methods and **electric propulsion system for vessels** will help achieving the 2011 White Paper's goal of reducing EU CO_2 emissions from maritime bunker fuels by 40% and can also help with the European Green Deal aims to reduce pollution in EU ports. With more efficient shipping routes and information provided to guide sustainable policies, **computer simulations modelling climatic impact on Arctic marine transportation**, can contribute to reducing transport emissions by 90%, as targeted in the European Green Deal, while, with more accurate simulations on the climate, better choices can be made in protecting and preserving it, in line with the 2016 EU Arctic policy. **Electric ferry** can help for a reduction in EU CO_2 emissions from maritime bunker fuels, aligning also with the European Green Deal reductions in transport emissions and a shift from road to inland waterway freight, as well as the reduction in pollution of EU ports. **Evacuation model validation data sets** has parallels to the 2011 White Paper goal of halving road casualties by 2020 and moving close to zero fatalities by 2050. This technology currently focuses on reducing casualties and fatalities in waterborne transport rather than road but there is some potential for the sensor and live information technology to carry down to road use.

The above technologies, address the needs of European policy recommendations, as detailed in the policy alignment sections, including the 2011 White Paper, and help meeting the European Green Deal's decarbonisation targets. An extensive overview of patent and research analysis on the above technologies highlight trends and the outlook.

In addition, the report includes a review of a selected limited number of technologies at a high development phase, identifying technologies that are likely to have an impact on products and operations in the short to medium term, and illustrating some that may contribute to products and systems that will be available in the shorter term. More specifically:

— **Public charging infrastructure** technologies provide a means of charging electric vehicles that is available for public use, with both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) can use this technology to charge the vehicle's battery. This technology can help with the Alternative Fuels Infrastructure's Directive requirement of introducing a minimum level of infrastructure for charging electric vehicles across the EU at one public charging point for every ten electric vehicles

- **Hydrogen production and refuelling** technologies that concern hydrogen as a transport fuel and have a higher development phase (i.e. more mature technologies), include the production of hydrogen using an electrolyser system and the refuelling of hydrogen by use of an ionic compressor. Hydrogen Europe predicts that hydrogen could account for 24% of the final energy demand across all sectors within Europe, and these technologies can help towards this goal.
- **Cockpit-based technologies for improved pilot workflow** are a group of technologies which aim to reduce pilots' peak workload and support them in dealing with difficult situations, thus enhancing safety and performance. With an average of 24 yearly fatalities in commercial flights across the period 2010-2018, there is still a real need for advances in cockpit-based technologies for improved pilot workflow.
- **ICT support systems for multimodality** technologies are used to bring multiple benefits to public organisations by providing real-time visibility, efficient data exchange and better flexibility to react to unexpected changes along the route. Future developments in this technology are focused on using big data and the IoT to develop machine-learning models to predict freight movements and improve multimodal operations The use of an IoT network could provide much more accurate real-time data, allowing for multimodal logistics operators to optimise the supply chain and reduce overall delays in the transportation of goods.

Findings can help stakeholders in transport innovation, including policy makers, regulators, transport service providers, and standardisation bodies. Furthermore, insights into the current status of these technologies and arising future needs helps the STRIA WGs to better assess R&I activities.

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List of abbreviations and definitions

3D	Three-dimensional
4G	4th Generation Mobile Communications Technology
5G	5th Generation Mobile Communications Technology
ACARE	Advisory Council for Aviation Research and Innovation in Europe
ACAS	Airborne collision avoidance systems
ALT	Low-emission alternative energy for transport
BEV	Battery electric vehicle
BEV	Battery electric vehicle
BLI	Boundary layer ingestion
BMS	Battery management system
BPR	Bypass ratio
CAT	Connected and automated transport
CEF	Connecting Europe Facility
CNG	Compressed natural gas
CO_2	Carbon dioxide
CORDIS	Community Research and Development Information Service
CPC	Cooperative Patent Classification
DG MOVE	Directorate-General for Mobility and Transport
DG RTD	Directorate-General for Research and Innovation
DMFC	Distributed multiple-fans concept
DSCR	Dedicated short range communications
EC	European Commission
ELT	Transport electrification
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
EV	Electric vehicle
FCEV	Fuel cell electric vehicle
FD-SOI	Fully depleted silicon on insulator
finFET	fin field-effect transistor
FP	Framework Programme
FP7	7th Framework Programme
GSM	Global system for mobile communications
H2020	Horizon 2020 Framework Programme
HGV	Heavy goods vehicle
HLFC	Hybrid laminar flow control
HMI	Human-machine interface
HVAC	Heating, ventilation and air-conditioning
ICAO	International Civil Aviation Organisation

ICE	Internal combustion engine
ICE	Internal combustion engine
IMO	International Maritime Organization
INF	Transport infrastructure
IoE	Internet of Everything
IoT	Internet of Things
IP	Intellectual Property
IR	Infrared
JRC	Joint Research Centre
LCA	Life cycle assessment
LOHC	Liquid organic hydrogen carriers
LSA	Life-saving appliances
LWIR	Long wavelength infrared
MEV	Mass evacuation vessel
NASA	National Aeronautics and Space Administration
NDI	Non-destructive investigation
NETT	New and emerging technologies and trends
NO_x	Nitrogen oxide
NTM	Network and traffic management systems
OEM	Original equipment manufacturer
OGV	Outlet guide vane
OPR	Overall engine pressure ratio
PATSTAT	EPO Worldwide Patent Statistical Database
PEV	Plug-in electric vehicle
PFC	Propulsive-fuselage concept
PHEV	Hybrid electric vehicle
PN	Particle number
R&I	Research and innovation
REGEX	Regular expressions
RTD	Response time distributions
SES	Single European Sky
SETIS	Strategic Energy Technologies Information System
SHM	Structural health monitoring
SMO	Smart mobility and services
SOC	State-of-charge
SOH	State-of-health
SOP	State-of-power
STRIA	Strategic Transport Research and Innovation Agenda
SUMP	Sustainable urban mobility plan

TEmSAL	Tailored embeddable sensor-actuator layers
TEN-T	Trans-European Transport Network
TRIMIS	Transport Research and Innovation Monitoring and Information System
TRL	Technology Readiness Levels
UHBR	Ultra-high bypass ratio
VCC	Vapour compression cycle
VDM	Vehicle design and manufacturing
VDES	VHF Data Exchange System
VHF	Very High Frequency
VTMIS	Vessel Traffic Monitoring & Information Systems
WG	Working group

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Annexes

Annex 1. Technology table of projects researching each technology

Project Acronym	Parent Programmes	Project Funding
Smart sensors and smart running gear components for self-diagnosis		
EXTREME	H2020-EU.3.4	€5,277,598
GRAILS-SWE	H2020-EU.3.4	€71,429
RUN2RAIL	H2020-EU.3.4	€211,969
OCEAN12	H2020-EU.2.1	€95,601,563
Ultra-high bypass ratio and pressure ratio aircraft engines		
TECC-AE	FP7-TRANSPORT	€11,945,706
KIAI	FP7-TRANSPORT	€7,822,016
LEMCOTEC	FP7-TRANSPORT	€67,909,374
JERONIMO	FP7-TRANSPORT	€7,361,403
NIPSE	H2020-EU.3.4	€6,235,001
DEMOS	H2020-EU.3.4	€410,450
CORNET	H2020-EU.3.4	€997,772
ASPIRE	H2020-EU.3.4	€3,406,735
ARCTIC	H2020-EU.3.4	€2,388,531
ORBIT	H2020-EU.3.4	€2,498,216
AFloWTest	H2020-EU.3.4	€942,500
AvAUNT	H2020-EU.3.4	€1,781,338
FINCAP	H2020-EU.3.4	€999,981
INAFLOWT	H2020-EU.3.4	€1,146,750
HILOGEAR	H2020-EU.3.4	€683,565
BIRAN	H2020-EU.3.4	€2,237,841
LPA GAM 2018	H2020-EU.3.4	€ 247,978,163
SKOPA	H2020-EU.3.4	€709,581
ANACO	H2020-EU.3.4	€2,257,999
IDA	H2020-EU.3.4	€513,243
PROTEUS	H2020-EU.3.4	€1,112,715
VibSEA	H2020-EU.3.4	€848,459

Project Acronym	Parent Programmes	Project Funding
TRUflow	H2020-EU.3.4	€2,514,805
On-board testing systems for ETCS		
EATS	FP7-TRANSPORT	€3,902,076
X2RAIL 3	Shift2Rail	€38,885,435
CNG fuelling station		
Green Connect - A public CNG network	CEF Transport	-
Hybrid laminar flow control		
LPA GAM 2018	H2020-EU.3.4	€247,978,163
Open platform concept for mobility services		
VIAJEO	FP7-TRANSPORT	€6,025,331
TT	H2020-EU.2.1.	€18,703,369
SELECT for Cities	H2020-EU.2.1.	€5,652,313
FreeWheel	H2020-EU.2.1.	€7,188,250
MW-R	H2020-EU.2.3.	€64,244
Truck platooning		
SARTRE	FP7-TRANSPORT	€6,933,054
COMPANION	FP7-ICT	€110,628
ENSEMBLE	H2020-EU.3.4.	€26,046,077
Predictive virtual testing of composite structures up to failure		
MAAXIMUS	FP7-TRANSPORT	€65,103,343
Holistic life cycle performance assessment methods		
BESST	FP7-TRANSPORT	€28,826,991
SLOWD	H2020-EU.3.4.	€3,156,751
Safety (and maintenance) improvement through automated flight data analysis		
SVETLANA	FP7-TRANSPORT	€3,920,503
MALORCA	H2020-EU.3.4	€805,588
EMPHASIS	H2020-EU.3.4.	€937,130
MIDAS	H2020-EU.3.4.	€1,154,375
ICE GENESIS	H2020-EU.3.4.	€21,980,550

Project Acronym	Parent Programmes	Project Funding
ADMITTED	H2020-EU.3.4.	€1,718,330
Battery management system module		
SUPERLIB	FP7-ICT	€6,548,215
SMART-LIC	FP7-ICT	€5,834,680
ESTRELIA	FP7-ICT	€6,870,559
INCOBAT	FP7-ICT	€5,786,665
HPCForEVs	H2020-EU.3.4.	€3,531,390
SmartCharge	H2020-EU.2.1., H2020-EU.2.3.	€71,429
VALERIE	MOTF - Mobility of the Future (Austria)	-
ALTOM	H2020-EU.2.3., H2020-EU.2.1.	€71,429
EV component modelling tools		
WIDE-MOB	FP7-TRANSPORT	€3,740,732
ASTERICS	FP7-TRANSPORT	€4,280,294
OBELICS	H2020-EU.3.4.	€9,077,498
HiFi-ELEMENTS	H2020-EU.3.4.	€7,532,319
PANDA	H2020-EU.3.4.	€3,488,671
Electric propulsion system for vessels		
MarketStudy-OV	H2020-EU.3.4.	€71,429
Port-Liner, "zero emission" ships for inland waterways.	CEF Transport	-
ACCEL BARGE	CEF Transport	-
Collision avoidance system		
HISVESTA	FP7-TRANSPORT	€3,136,667
ARTRAC	FP7-TRANSPORT	€4,022,551
AMOR	H2020-EU.3.4.	€2,028,950
AGENT	H2020-EU.3.4.	€598,750
PJ11 CAPITO	H2020-EU.3.4.	€15,393,839
SENSORIANCE	H2020-EU.3.4.	€1,572,750
Nanomaterials for structural health monitoring		
SARISTU	FP7-TRANSPORT	€50,712,428

Project Acronym	Parent Programmes	Project Funding
Hydrogen storage system		
HYDRUS	H2020-EU.3.4.	€71,429
Hydrogenlogistics	H2020-EU.3.4.	€3,260,269
TAHYA	H2020-EU.3.4.	€3,996,944
KC4HiPS	MOTF - Mobility of the Future (Austria)	-
HySTOC	H2020-EU.3.3.	€2,499,921
PURE H2	CEF Transport	-
THOR	H2020-EU.3.4.	€2,853,959
Vehicle energy management systems		
HEATRECAR	FP7-TRANSPORT	€4,240,834
ICT-EMISSIONS	FP7-ICT	€4,698,791
MAXITHERM	H2020-EU.3.4.	€71,429
XERIC	H2020-EU.3.4.	€4,621,280
MAXITHERM 2	H2020-EU.3.4.	€2,185,094
ACHILES	H2020-EU.3.4.	€6,093,474
OSCD	MOTF - Mobility of the Future (Austria)	-
Computer simulations modelling climatic impact on Arctic marine transportation		
ACCESS	FP7-TRANSPORT	€14,848,399
SEDNA	H2020-EU.3.4.	€6,726,565
Electric ferry		
E-ferry	H2020-EU.3.4.	€21,303,821
Evacuation model validation data sets		
SAFEGUARD	FP7-TRANSPORT	€3,655,826
SafePASS	H2020-EU.3.4.	€8,270,366
PALAEMON	H2020-EU.3.4.	€8,943,776

Source: TRIMIS

Annex 2. Table of CPS codes and keywords for the patent analysis

Technology	CPC code	Relevant CPC code description	Keywords
Smart sensors and smart running gear components for self-diagnosis	N/A	N/A	"self-diagnosis"
Ultra-high bypass ratio and pressure ratio aircraft engines	N/A	N/A	"bypass ratio" OR "pressure ratio"
Mobile CNG Fuelling	B60	VEHICLES IN GENERAL	"CNG" OR "natural gas" OR "LNG"
On-board testing systems for ETCS	B61L	GUIDING RAILWAY TRAFFIC; ENSURING THE SAFETY OF RAILWAY TRAFFIC	"ETCS" OR "train control system"
Open platform concept for mobility services	N/A	N/A	"service" AND "platform" AND "open"
Truck platooning	B60	VEHICLES IN GENERAL	"platooning" OR "platoon'"
Predictive virtual testing of composite structures up to failure	N/A	N/A	("testing" OR "simulation") AND "composite"
Holistic life cycle performance assessment methods	N/A	N/A	("life cycle" OR "lifecycle" OR "life-cycle") AND "method"
Safety (and maintenance) improvement through automated flight data analysis	G08G5	Traffic control systems for aircraft	"data"
Battery management system module	B60L	SUPPLYING ELECTRIC POWER FOR AUXILIARY EQUIPMENT OF ELECTRICALLY-PROPELLED VEHICLES	'Battery management system'
EV component modelling tools	N/A	N/A	"electric vehicle" AND "component" AND "model"
Electric propulsion system for vessels	B63H 21/17	MARINE PROPULSION OR STEERING BY ELECTRIC MOTOR	"ship" OR "vessel"
Hybrid laminar flow control	B64C	AEROPLANES; HELICOPTERS	" flow control "
Collision avoidance system	G08G	TRAFFIC CONTROL SYSTEMS	"collision avoidance"
Nanomaterials for structural health monitoring	N/A	N/A	"structural monitoring" OR "structural health monitoring" OR "structural damage"

Technology	CPC code	Relevant CPC code description	Keywords
Hydrogen storage system	B60K	ARRANGEMENTS IN CONNECTION WITH COOLING, AIR INTAKE, GAS EXHAUST OR FUEL SUPPLY OF PROPULSION UNITS IN VEHICLES	"hydrogen"
Vehicle energy management systems	B60W	CONJOINT CONTROL OF VEHICLE SUB-UNITS OF DIFFERENT TYPE OR DIFFERENT FUNCTION;	"energy management"
Computer simulations modelling climatic impact on Arctic marine transportation	B63	SHIPS OR OTHER WATERBORNE VESSELS; RELATED EQUIPMENT	"arctic"
Electric ferry	N/A	N/A	"electric boat" OR "electric ferry" OR "electric ship"
Evacuation model validation data-sets	N/A	N/A	("ship" OR "boat" OR "waterborne") AND "evacuation"

Source: Own elaborations

Annex 3. REGEX for the Scopus analysis

Overview of research in Scopus in 2010-2019 under social sciences and “transport”

(PUBYEAR>2009) AND (PUBYEAR<202) and TITLE-ABS-KEY(transport) and SUBJAREA(SOCI)

Technology 1 (TITLE-ABS-KEY("diagnosis" and aircraft and sensor) and PUBYEAR>2009 AND PUBYEAR<2020)

Technology 2 (TITLE-ABS-KEY("ultra high bypass") and PUBYEAR>2009 AND PUBYEAR<2020)

Technology 3 (TITLE-ABS-KEY(etcs and rail) AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 4 (TITLE-ABS-KEY(("refuelling" or "refueling") and (CNG or "compressed Natural Gas")) AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 5 (TITLE-ABS-KEY("hybrid laminar flow control ") and PUBYEAR>2009 AND PUBYEAR<2020)

Technology 6 (TITLE-ABS-KEY ("mobility on demand" OR "mobility as a service") AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 7 (TITLE-ABS-KEY ("platooning" and (truck or vehicle)) AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 8 (TITLE-ABS-KEY (aircraft or airplane) and "composite structure" and simulation) AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 9 (TITLE-ABS-KEY(("life cycle assessment") and ("vessel" or maritime or boat)) AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 10 (TITLE-ABS-KEY("flight data" and ("data management" or "data analysis")) AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 11 (TITLE-ABS-KEY(vehicle and (("Battery management system") or BMS)) AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 12 (TITLE-ABS-KEY("electric vehicle" and component and ("simulation" or modelling or modeling)) AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 13 (TITLE-ABS-KEY("Electric propulsion" and (vessel or ferry or ship)) AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 14 (TITLE-ABS-KEY("Collision avoidance system" and (car or vehicle)) AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 15 (TITLE-ABS-KEY(("damage detection" or "structural health monitoring" or SHM) and wing) AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 16 (TITLE-ABS-KEY(vehicle and "hydrogen storage") AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 17 (TITLE-ABS-KEY("energy management" AND "electric vehicle") AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 18 (TITLE-ABS-KEY((arctic and marine and simulation)) AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 19 (TITLE-ABS-KEY(("Electric ferry" or "electric vessel" or "electric ship")) AND (PUBYEAR>2009) AND (PUBYEAR<2020))

Technology 20 (TITLE-ABS-KEY("evacuation model" or "emergency evacuation" and ("ferry" or "vessel" or "ship")) AND (PUBYEAR>2009) AND (PUBYEAR<2020))

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