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Connected and Automated Transport: Research and Innovation Capacity in Europe

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Abstract

Evaluating the future impacts of transport innovation on society is notoriously difficult. Yet foresight and monitoring tools are important to anticipate on possible futures so that research funding and policy making efforts can be guided. This paper presents a comprehensive two-tiered approach to 1) identify new and emerging technologies and trends in transport and 2) leverage a transport research database and analysis tool to assess the current status of transport research and innovation. The approach is applied to the field of Connected and Automated Transport (CAT). The level of public investment is identified and the geographical distribution of research organizations shown. We argue that this approach can aid policy makers to support the future development of CAT technologies and help researchers to forge collaborations and identify research gaps.

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Keywords: Connected and Automated Transport; Capacity Maps; New and Emerging Technologies; Transport R&I

1. Introduction

Transport is one of the main pillars of development. It comprising a spectrum of individual systems and their interconnections that are intended to cover the mobility demand of people and goods. Transport systems include an extensive series of physical and organizational elements and are being characterized by an overall intrinsic complexity. These elements can be influencing each other directly and/or indirectly, linearly or nonlinearly, having also potential feedback cycles (Cascetta, 2001). In the above sense, the transport system can be considered as an infrastructural and human system and it can be referred to as a Complex, Large-scale, Interconnected, Open, Socio-technical (CLIOS) system, including elements from the built environment and the social-political domains.

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The impact of any change in a transport subsystem, even if predictable separately, can be difficult to anticipate and even seem counterintuitive (Sussman et al. 2009). Furthermore, transport innovation covers more than technical hardware. Even though it may often comprise mostly technical elements, the organizational innovations and new mobility concepts which do not require hardware modifications can be also regarded as innovations as they aim to use hardware in a different manner (Weber et al. 1999). In particular, new technologies and transport trends add new levels of complexity and can considerable influence people mobility and freight transport services.

One of the more discussed transport technologies in the last years concerns autonomous vehicles. Connected and automated transport (CAT) technologies can contribute to increasing the efficiency and safety of the transport system. They can also improve traffic flows, optimize infrastructure and public transport usage and foster multi-modal transport solutions. In the last years, they have become are a trending area in transport research and innovation both for private companies and the public sector. Lower levels of connectivity and automation are nowadays a reality, for more advanced levels, further testing is necessary, together with policy and legislation related initiatives. For this, a number of pilot demonstrations of CAT technologies are planned, focusing on the technological readiness, reliability and safety of automated transport functions in complex situations.

CAT technologies cover all transport modes (road, rail, maritime and air) with issues and challenges that are either cross-modal or mode-specific. Nevertheless, a massive hype has been surrounding CAT in the road sector, with autonomous vehicles being at the peak of inflated expectations in 2015 in the Gartner Hype Curve (Gartner, 2018). For road, the uncertainty in predicting the impacts of CAT remains high given the intrinsic complexity of the transport system. In fact, even after several years of testing, remains unclear how Connected and Automated Vehicles (CAVs), mixed with conventional legacy vehicles, will behave in real traffic (Ciuffo et al. 2018), while, their potential impacts in energy/fuel efficiency could be partially outweighed by higher travelling speeds (Makridis et al. 2017). According to ERTRAC (2017), automated driving can support several of the EU objectives and societal challenges, such as road safety, congestion, decarbonisation and social inclusiveness.

In the other modes of transport (aviation, railway and maritime), connectivity and automation have been present in different forms since the early days. Autonomous airplanes under development are not foreseen in the next decade, while an intermediate step could be a single-pilot operation. On the other side, both developments require the trust by the passengers and stakeholders. Automatic train operation is well established on metro systems in Europe and around the world, with improvements in train regularity and consumption, and a further expansion is expected to main railway lines. Autonomous ships are under development; however, the economic advantages of full automation are not clear, and several steps need to be implemented from navigation automation to fully autonomous navigation (Lloyds Register, 2016). Thus, on all three modes of transport, future developments seem more evolutionary than revolutionary compared to the road sector.

That said, different horizontal areas play a vital role in the CAT successful implementation. Digital connectivity in particular, is important in addressing key issues such as the performance of innovative automated transport technologies, the regulatory framework that supports deployment of CAT solutions and technologies, acceptable levels of cybersecurity, as well as new business models. Hence, in order for CAT technologies to positively impact society there is a range of conditions that need to be put in place. For this it is important that forecast and monitor systems are being put in place.

Whilst acknowledging the challenges of transport innovation monitoring, we emphasize its importance to steer funding and anticipate on future technologies. To that end we developed a two-tiered approach. After providing a an overview of issues and challenges in Section 2, we present in Section 3 the first step concerning a methodology to identify and monitor New and Emerging Technologies and Trends (NETT) in transport. The consequent step concerns the monitoring of research and innovation (R&I) capacity, as described in Section 4. Finally, conclusions are drawn and future work is discussed in Section 5.

2. Technological challenges, opportunities and policy perspective

In 2017, the European Commission (EC) adopted the Strategic Transport Research and Innovation Agenda (STRIA) as part of the "Europe on the move" package, which highlights main transport research and innovation (R&I) areas and priorities for clean, connected and competitive mobility to complement the 2015 Strategic Energy Technology Plan (European Commission, 2015, 2017).

This section focuses on challenges and opportunities in CAT. The identified issues are by no means exhaustive, but provide a top level indication that can be broken down to detailed and technical issues, and extended to different modes. These are accompanied with pertinent legislative initiatives in Europe (Fig. 1).

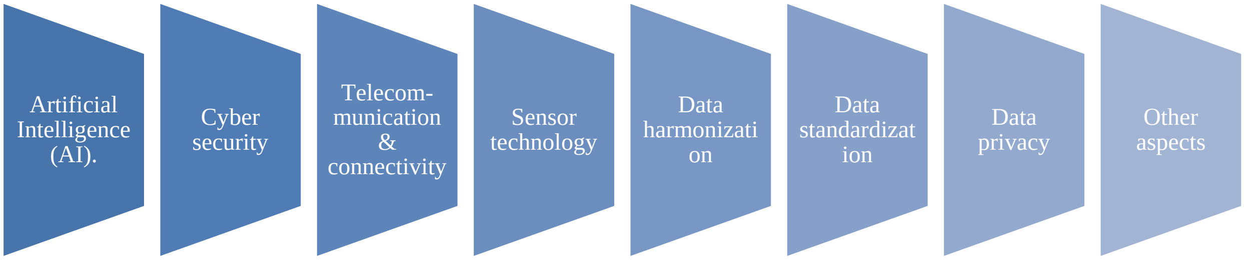

Fig. 1. Challenges and opportunities in CAT

- Artificial Intelligence (AI). AI is a cornerstone of the decision-making process in a connected and automated environment, and includes all processes related to learning, reasoning and behaving. Artificial Intelligence will become increasingly important in semi-autonomous and autonomous mobility. Europe's current ecosystem on AI is identified in an initial snapshot of the European AI landscape (European Commission, 2018a).
- Cybersecurity. The proliferation of connected and autonomous means of transport will raise cybersecurity risks, due to the increased amount of interconnected digital components in vehicles, their external connectivity (i.e., the connected part) and the increasing reliance on Artificial Intelligence algorithms and sophisticated sensors (e.g., the autonomous part). These issues are likely to become even more important with semi-autonomous or autonomous vehicle and it is important to define a strategy and related policies to foster the design and implementation of security solutions in vehicles and road infrastructure in general (European Commission, 2016).
- Telecommunications and connectivity. Personal road vehicles and self-driving trucks in platooning mode (ACEA, 2017) – that is, trucks using connectivity and automation to follow each other at a very short distance to save fuel and reduce CO2 emissions – will need to exchange information amongst them on a frequent basis (Vehicle-to-Vehicle, V2V) as well as with the communications infrastructure (Vehicle-to-Infrastructure, V2I). To this extent, V2V and V2I communications will become key enablers for the successful deployment of CAT. At the time of writing, two communications standards have been proposed for short-range V2V services, namely ITS G5 (based on enhancements to current WiFi standards) and LTE-V2X (based on enhancements to cellular communications standards).
- Sensor technology. Sensors for autonomous vehicles will become smaller, cheaper and more integrated. Modularity and sampling rate will be crucial for the successful deployment. In the last 5-10 years, there has been a growing dependency of vehicles on sensors and computing platforms able to process the sensor data in an increasingly sophisticated way to implement advanced driver-assistance systems such as electronic stability control, anti-lock brakes, lane departure warning, adaptive cruise control and traction control (Fleming, 2013).
- Data standardization, harmonization and privacy. With the availability of Big Data, accessibility and standardisation will be vital for the successful employment of digital technologies in the transport sector, especially in the connected environment. Data exchange will be crucial for the future development and success of CAT. Data will need to have a standard format that will allow the seamless exchange between vehicles and infrastructure and will form the basis for interoperability both at European level and also among the main elements of the road transportation infrastructure. The development of Cooperative Intelligent Transport Systems (C-ITS) in Europe is based on various standards defined in European Standardizations Organizations (ESO) or International ones (e.g., ISO, IEEE). Standards are needed to ensure interoperability at European and International level and to define harmonized processes (e.g., testing, operations), which support economies of scale in the market. It is important that the standardization process in Europe for C-ITS is both: a) innovative to take in consideration new technological developments and b) closely integrated with the regulatory

frameworks. In particular in the aspects of privacy, the European Commission's November 30 Communication on C-ITS (European Commission, 2016) emphasizes that data sharing must comply with data protection rules and aims to facilitate the adoption of the appropriate legal framework at EU level by 2018 to ensure legal certainty investors and end-users. A legal framework throughout the EU, thus, should regulate the data exchanged in a connected environment, ensuring privacy concerns. The process will need to clarify aspects such as who owns and who has direct access to the vehicle-generated data. The DT of information exchange has the potential to significantly improve the efficiency also of freight transport and therefore to contribute to the smooth functioning of the digital single market. Currently, the European Commission has published a proposal (European Commission, 2018b) which aims to foster the use of digital documentation in freight transport, ensuring interoperability and providing solutions for the electronic exchange of freight transport information. Truck Platooning will benefit from the standardisation of data of vehicle communication protocols across different brands (European Commission, 2018c). The three-year ENSEMBLE (Enabling SafE Multi-Brand pLatooning for Europe) project, which received EUR 20 million EU funding, will start in summer 2018 and will support the standardisation of communication protocols for multi-brand platooning.

- Other aspects. Another aspect of interest for future mobility is the regulation of unmanned aircraft systems (UAS). A legislation is under development following an agreement endorsed by the EU, reached with the European Parliament, on Dec. 22, 2017 (EASA, 2018). This would allow a high degree of flexibility from MSs so they can define zones in their territory where either drones operations are prohibited or restricted (for example to protect sensitive areas), or where certain requirements are alleviated.

The identified issues complement ongoing cross-sectorial activities (e.g. on vehicle design, electrification) necessary for a transition to CAT. They also interact with other emerging trends such as the Shared mobility and Mobility as a service (Holmberg et al. 2016), that enables users to gain short-term access to transportation modes on an "as-needed" basis, and the integration with smart cities. All these strongly influence the technological developments in terms or R&I.

3. Identification, inventory and assessment of new and emerging transport technologies and trends

In order to address current socio-economic challenges within an ever-changing complex and competitive environment, the transport sector requires new technological developments. This will be achieved through R&I that allows new quality standards in the mobility of people and goods. In 2017, the European Commission adopted the Strategic Transport Research and Innovation Agenda (STRIA) as part of the "Europe on the move" package, which highlights main transport research and innovation (R&I) areas and priorities for clean, connected and competitive mobility (European Commission, 2017). The STRIA has identified priority areas with specific actions for future R&I, outlined in seven roadmaps. One of them is cooperative, connected and automated transport.

The implementation of STRIA needs to be supported by an effective monitoring and information mechanism that assists the development and updating of STRIA and supports transport R&I. The EC Joint Research Centre (JRC) has developed the Transport Research and Innovation Monitoring and Information System (TRIMIS) in order to provide a holistic assessment of technology trends, transport R&I capacities, to publish information, data, and to develop analytical tools on the European transport system (Tsakalidis et al. 2018a). TRIMIS has been funded under the Horizon2020 Work Programme 2016-2017 on smart, green and integrated transport.

TRIMIS monitors developments in transport R&I and related sectors to assess the status of new technologies and their possible future implementation by creating a transport R&I database (i.e. data collection and setting up of a database) and by providing a continuous assessment of the transport sector and technology performance. One of the sub-tasks of TRIMIS is the creation of inventory and regular reporting on future and emerging technologies in the transport sector. The methodological framework for the inventory, modelling and assessment of new and emerging technologies and trends in transport (which builds on Gkoumas et al. 2018) is reported below.

The NETT inventory will not include technologies in the strict sense but also innovation in the transport sector in general (including innovative transport trends and initiatives). The process is based on the activities shown in the flowchart of Fig. 2.

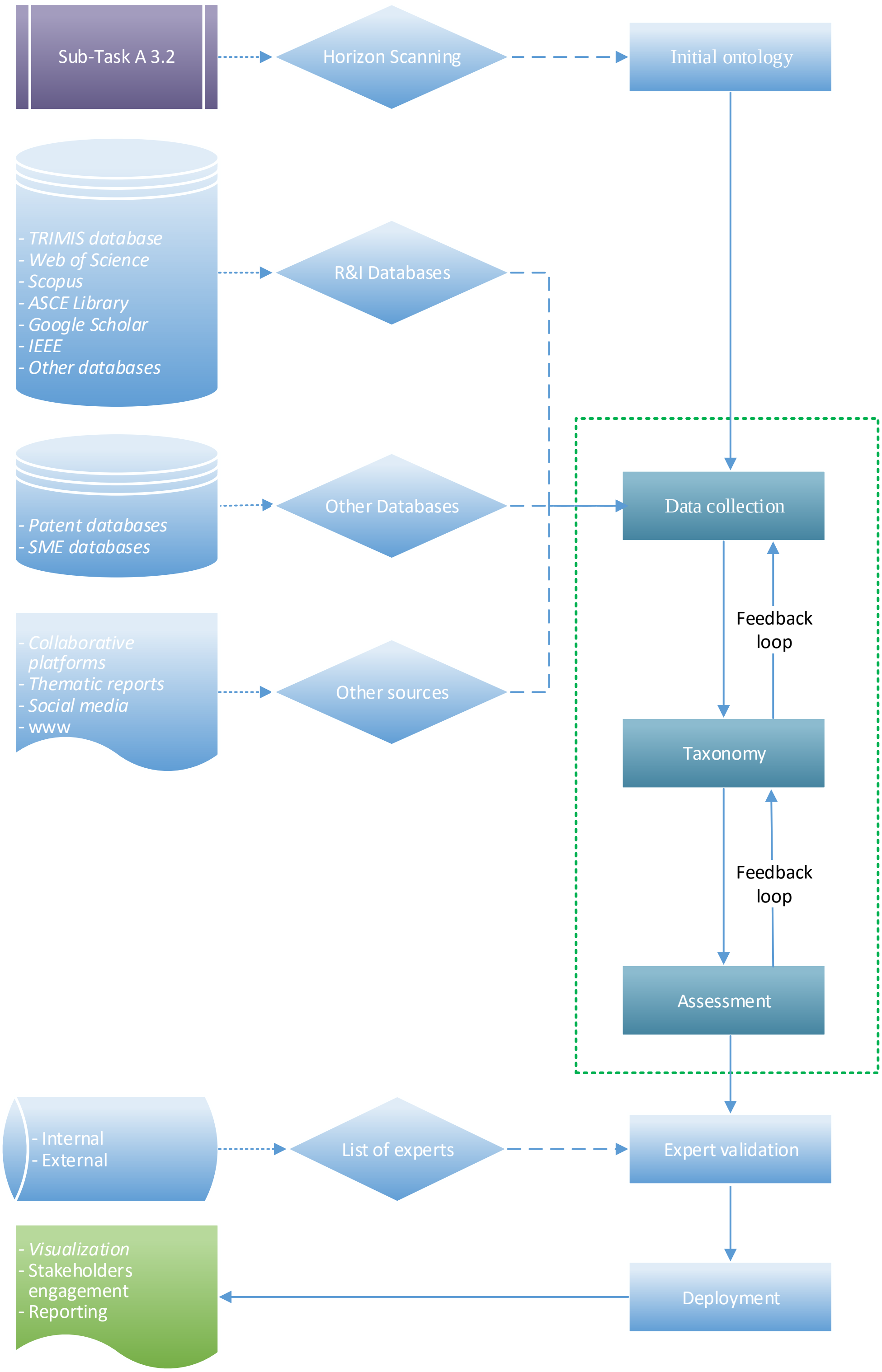

Fig. 2. Activities for building an inventory of NETT in transport

Among the identified activities, the following are considered as the principal:

- Horizon scanning
- Initial ontology of terms
- Data collection (key process)
- Taxonomy building (key process)
- Assessment (key process)
- Expert consultation
- Deployment of results (visualization and reporting)

The following sections focus on the three key processes mentioned above, which are relevant to this study: data collection, taxonomy building and assessment.

3.1. Data collection

This process includes several steps that secure the as-complete-as possible collection of data for the taxonomy. The taxonomy of NETT in transport will be build, spanning the entire transport sector, including connections with its interdependencies (e.g. energy, economy, construction).

The identification of R&I data sources that contain data relevant to transport is the next step in the methodology. Both traditional sources (e.g. databases) and Big Data sources (e.g. the World Wide Web - www) are considered.

Nevertheless, in the present study, the source of data considered is the TRIMIS database (Pekar et al. 2017), which at the time of the analyses included 6.500 European or EU Member state projects. The analysis focuses on European Union (EU) co-funded projects that cover all modes of transport.

The data in the database are collected and organized in a taxonomy, which is currently being build, with the intention to embrace the entire transport ecosystem.

3.2. Taxonomy

The developed taxonomy has the purpose of including all possible transport technologies and applications, including horizontal enablers, and is being developed in several levels. The taxonomy is developed in a database application, using appropriate tags and using a hybrid top-down and bottom-up process following the concurrent data gathering, the continuous horizon scanning and expert judgement. The parallel database development allows crosschecking instantly the relevance to different aspects. Currently, the taxonomy follows a strict model, in the form of a hierarchical network diagram, in the sense provided in the original paper by Simon (1962).

The taxonomy has different dimensions, the principal one being spatial, which includes different levels of detail (i.e. scales). The number of scales can be either fixed or dynamic.

This subdivision allows to organise hierarchically the elements and to compare, cross check or perform statistical analysis on elements of the same level. In the reference case, the number of scales is set to four, defined in the following manner:

1. Mega-scale. This is the broadest class and includes major areas of the transport sector or complete transport sub-systems. Examples in this category are the transport “mega trends”, e.g. autonomous vehicles, electric vehicles, high-speed vacuum tube transport, mobility as a service.
2. Macro-scale. This class comprises main elements of sub-systems. Examples may include a single autonomous vehicle, a single electric vehicle, a single transport infrastructure etc. Elements of this class shape a single element of the higher scale.
3. Meso-scale. This class includes the principal elements of a macro-scale element. For an electric vehicle for example, meso-scale elements include the propulsion system (engine), the electric system, the gear system, etc.
4. Micro-scale. This is the lowest level class and includes individual elements that constitute a meso-scale subsystem. Using again an electric vehicle as an example, a micro scale element can be the battery, which is a component of the electric system.

Fig. 3 depicts the concept in a matrix format. From left to right, the scales represent the different levels of the taxonomy. For each scale (columns in the figure), the different elements or components are organised in a non-hierarchical manner. Each element at a lower scale is linked to its parent element at a scale above (horizontal organisation). As stated before, the taxonomy elements can be both tangible and intangible, depending also on the scale.

Additional dimensions are also considered for the taxonomy. In Fig. 3 for example, time is also shown. This dimension can be useful for comparing the evolution and for depicting trends (forward thinking) and lessons learned (backward learning). It can be also customised to rank selected chronological time instances (e.g. time of presentation, time of maturity, time of withdrawal). These instances will be linked to each element individually, but for assessment purposes, a time-frame can be established. Since the taxonomy will be organised in a matrix form, the linking to an appropriate database format will be direct, something that will help integration with existing transport databases or innovation and technical development tools. This will lead to the possibility of linking different levels of the taxonomy with R&I (either public or private) using available R&I data.

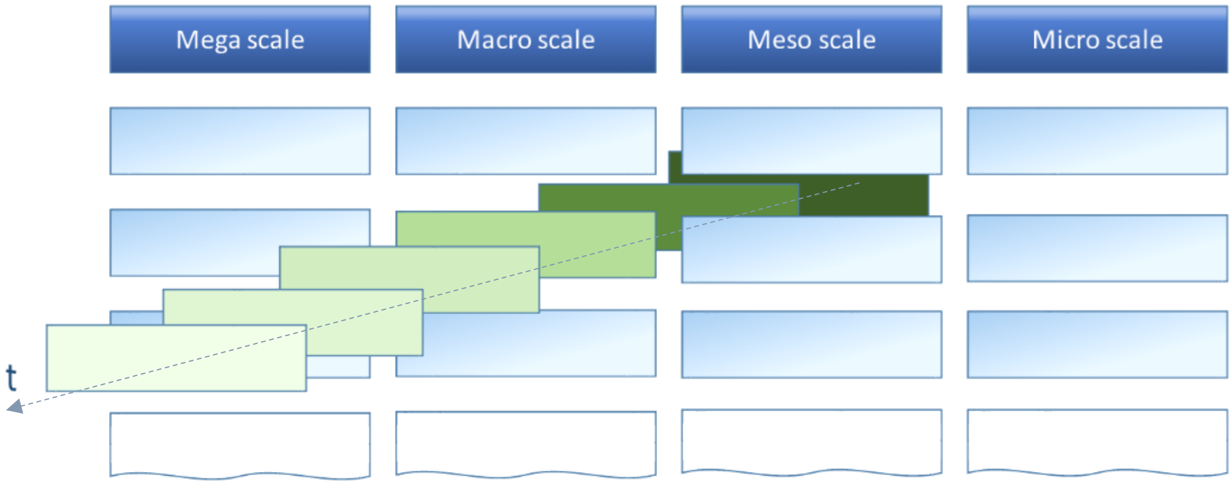

Fig. 3. Spatial dimension of the taxonomy with time-based layers

Data in the taxonomy provide the input for the assessment of NETT in transport.

3.3. Assessment

Different methods with different levels of detail are used for the assessment of different technology and trends scales. For system parts or components, simple assessment based on set key performance indicators (KPIs) or other indices (e.g. efficiency indices) is adequate. For large-scale technologies, technology acceptance models or surveys are more appropriate.

Using a hierarchic taxonomy for each technology, it is possible to adjust in real time the performance in relation to components or parts belonging to a lower level in the taxonomy. In the same way, it is possible to obtain an assessment limited by other attributes in the taxonomy (e.g. geographic availability of components or parts) and, after a calibration, perform comparative analysis for different scenarios corresponding to changes in the attributes of specific components.

In the assessment of R&I it is important to consider readiness levels as KPIs in order to foresee the time of introduction of a new technology. However, for some sectors, it is imperative to also consider socio-economic criteria (e.g. their potential impact and rate of social acceptance). The assessment method is tailored to the specific level and the dependencies from lower levels are reflected and can be compared to either static thresholds or temporal comparisons. For example, a low readiness level in a component of a system may prove to be a bottleneck for the entire system.

The assessment in this study is limited to socio-economic aspects, and aims to show trends and opportunities, using geographical filtering.

4. CAT R&I Capacity in Europe

The results in this section build on the TRIMIS database, which is a large repository of publicly funded transport research projects with a predominant focus on Europe (Tsakalidis et al. 2018b). To assess the research efforts in Europe we categorised each project under one of the seven key fields of transport innovation as defined by the abovementioned STRIA initiative, one of which being CAT. The projects are also categorised on various other variables, including mode of transport.

The described NETT methodology identified a range of technologies within the field of CAT. For the purpose of this paper we do not disaggregate the analyses per CAT technology, but rather present some results for the field as a whole. By doing so we define the broader context in which CAT R&I occurs.

In Fig. 4 the total average daily investments in CAT research are presented. The daily spending was determined by taking a simple average of the total project funding by the number of days the project should last. The spending is based on the total project costs of the three most recent European framework programmes. The costs are covered by grants, as well as contributions by the project participants.

Whilst the analyses below do not cover nationally or private funded research, we consider these framework programmes important enough to develop a good understanding on the status of research in various fields, as the framework programmes are the largest coordinated research programmes on the continent.

The figure shows three bell curves that are indicative of the start and end date of the respective programmes. We also note that the Horizon 2020 (H2020) framework programme (Cordis, 2018) is still ongoing and therefore is likely to grow. The spending on CAT research shows a steady increase, peaking at about EUR 400.000 a day.

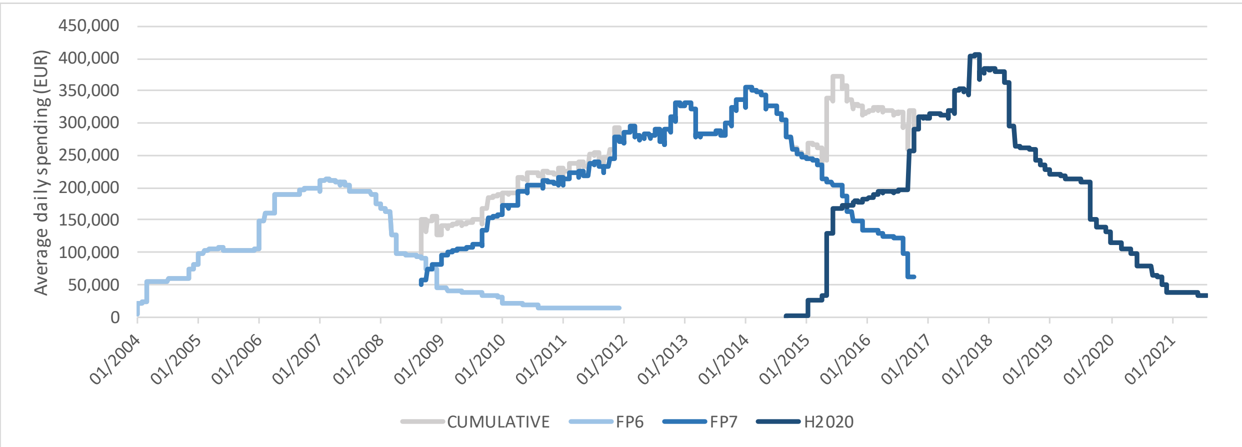

Fig. 4. Spending on CAT R&I through European Framework Programmes (source: TRIMIS – March 2018)

Fig. 5 provides a snap shot of research under the Horizon 2020 framework programme, showing on which modes of transport the projects focus, specifically:

- Road
- Rail
- Waterborne
- Air
- Urban
- Multimodal
- Other

Road transport remains the dominant field of research, with rail coming in second. Waterborne transport appears to receive considerable less attention in terms of CAT research. While not strictly a mode in itself, urban transport was also included to understand the extent of CAR research with a focus on city transport. The multimodal category appears large. The reason can be partially explained by the type of projects that are financed, as some projects develop technologies that can be applied to several modes. A methodological reason for the size of the category is that projects under both road and urban transport were categorized as multimodal projects.

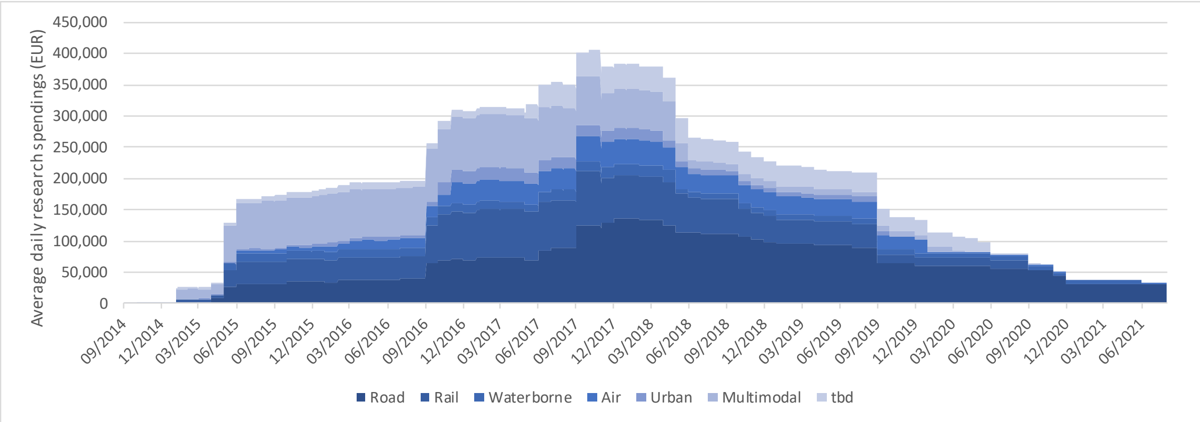

Fig. 5. Spending on CAT R&I per transport mode under Horizon 2020 (source: TRIMIS – March 2018)

The final figure below, Fig. 6, shows the geographical distribution of research organizations in the field of CAT.

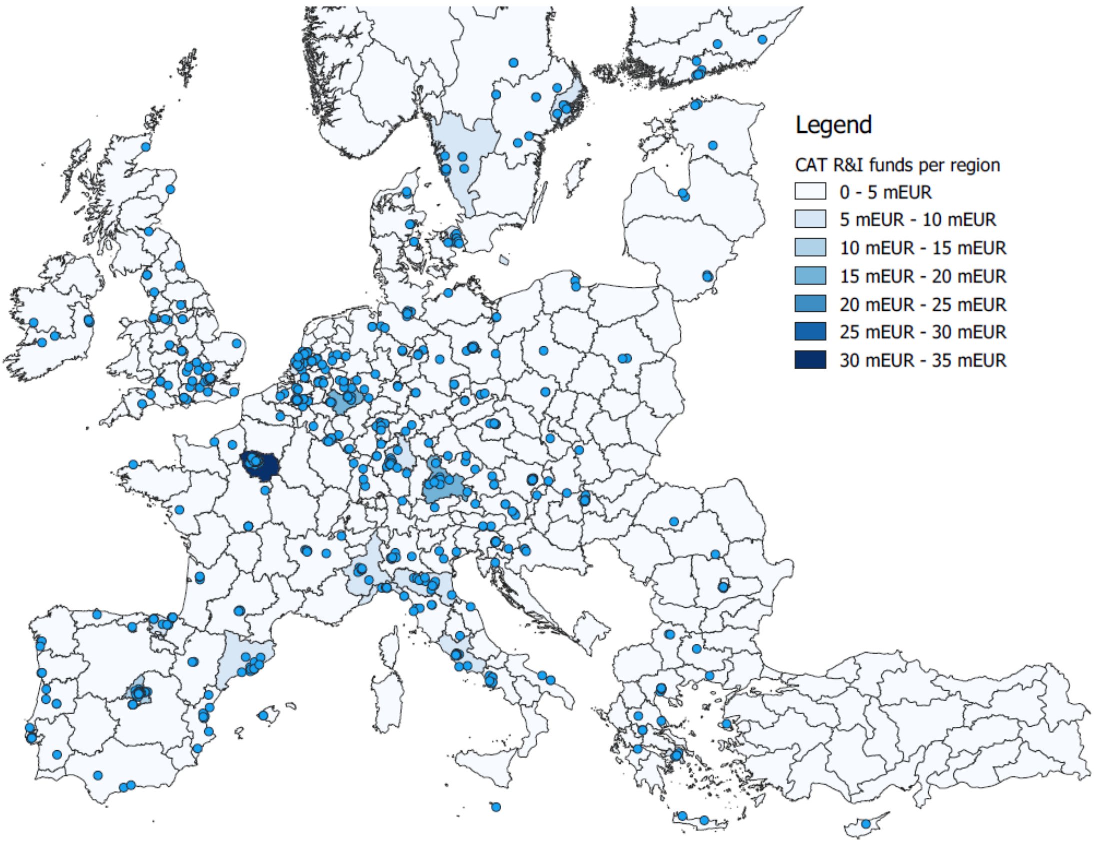

Fig. 6. Geographic distribution of CAT R&I organizations under Horizon 2020 (source: TRIMIS – March 2018)

All beneficiaries of H2020 funds have been identified and highlighted with a dot. The cumulative resources per region on Nomenclature of territorial units for statistics (NUTS) 2 level (Eurostat, 2018) are also added as a separate layer. The research organizations appear to be clustered around the locations of the large car manufacturers (e.g. southern Germany, Northern Italy, Île-de-France). In addition, a number of Western European agglomerations and university cities are also well represented.

The results above give a rudimentary but important overview on the direction and location of CAT R&I across Europe. Having an understanding on the locations can aid policy makers to identify clusters and regional research specializations. In addition, the resources invested in various modes of transport can be indicative of the pace of change in some modes, and research gaps in other. Such information can be beneficial to define future research programmes.

5. Conclusions

This paper outlines a methodology for the Modelling and Assessment of New and Emerging Technologies and Trends (NETT) in the transport sector. The methodology tries to address two principal challenges:

1. The complexity of the transport sector, especially in recent times of possible disruptions emerging from the digital transformation of the society.
2. The practical implementation of the methodology that will lead to an as much as comprehensive assessment.

An initial outcome of the proposed methodology focuses into the status of CAT R&I across Europe and provides insights from several perspectives.

Principal findings show that the spending on CAT research through framework programmes has increased over time. It was moreover observed that significant drops in funding exist between the ending and start of each FP. The project timelines that were presented in this report could be used as an instrument to detect drops in funding per transport mode. For instance, while road transport enjoys a continuous number of projects of different sizes, projects on multimodal transport seem to be largely finished by 2018. Overall it was observed that road transport is the mode that receives greatest interest in terms of total funding and the number of organisations that are researching CAT. Using spatial analysis it was shown that most CAT research organisations are located in the proximity of car manufacturers, as well as in large urban centres in Western Europe and university cities.

The analysis is subject to several limitations. The most recent H2020 projects were not yet categorized, and are therefore not included. Nevertheless, this report does offer a comprehensive and up-to-date overview on the capacity of CAT research across Europe.

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