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A FRAMEWORK FOR THE TAXONOMY AND ASSESSMENT OF NEW AND EMERGING TRANSPORT TECHNOLOGIES AND TRENDS

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Abstract. This paper focuses on the development of a taxonomy framework for new and emerging technologies and trends in the transport sector. This framework is proposed towards the assessment and monitoring of the acceptance, impact and diffusion of technologies and trends, together with a scoring system and a front–end visualisation of the outcomes. In this context, an overview of the transport technology hype over the last years and the establishment of future transport technologies and trends is provided. Issues arising from different constraints, including technological and technical, are taken into account, also considering the transport sector's interconnection with other sectors and potentially related bottlenecks and drawbacks. The paper outcome is a methodological framework for the creation of different taxonomies for new and emerging transport technologies and trends, achieved through the quantitative assessment of the attractiveness and competitiveness, in terms of diffusion potential, of emerging transport technologies and trends, by associating explicit indices to the various elements of the taxonomies. The proposed taxonomy, assessment and monitoring framework supports innovation management through the identification and evaluation of new and emerging technologies and trends in the field of transport at various levels, thus providing insights to the sector's stakeholders, while backing the current transport systems' transformation through technological advances.

Keywords: transport sector, technological innovation, taxonomy, new emerging technologies, technology hype, disruptive innovation, knowledge management.

Introduction

Transport is one of the main pillars of development 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 organisational elements and are being characterised by an overall intrinsic complexity. Those elements can be influencing each other directly and/or indirectly, linearly or nonlinearly, having also potential feedback cycles (Cascetta 2001). Along with the general technological development, the technological applications found across the various transport systems and subsystems have been increasing in numbers and level of complexity, often following the latest technological trends falling either within or outside the transport sector. The assessment of new and emerging transport technologies and trends is delicate, since often their performance can be tested only in virtual conditions e.g. using scenario-planning methods (Mazzarino 2012) and without reliable information of their potential deployment. Furthermore, their acceptance is conditioned principally by the human factor, interlinked to current social issues (e.g. safety, security, sustainability, climate change), including the influence from social interaction (Axsen, Kurani 2012). On top of that, society often shows reluctance in accepting new technologies (Heiskanen *et al.* 2007), something that may become more evident during a period of rapid technological advance. This deceleration phenomenon could be further intensified due to possible bottlenecks in the design and implementation phase of new technologies and services, also being directly and indirectly affected by multiple individual system factors (e.g. supply chain problems, policy decisions, regulations and standards).

In this context, during the past few years, several concepts, trends and technologies have been identified at times as being potentially the "next big thing" in transport. Mobility as a service for example is a trending option for commuters, while Connected and Automated Vehicles (CAVs) are extensively tested with a foreseeable large-

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scale deployment in the next 10 years (Arbib, Seba 2017). The methodological identification, reporting and updating of new emerging transport technologies and trends, along with their associated benefits, implementation challenges, and risks, is one of the principal strategic objectives of academia, industry, policy agencies and analysts and has big social implications. Potential technological advances and innovations that are deployed in order to face the often-systemic nature of transport-related challenges are part of a greater transport system that is constructed from a series of aligned elements (Auvinen, Tuominen 2014). To this aim, a taxonomy that identifies and links those elements, including transport trends, technologies and concepts, both past and future, can be helpful for the prompt identification of issues regarding their deployment, including the possible modal shift towards new mobility options and services. Such taxonomy can help accelerating the implementation rate of new transport technologies and trends by identifying critical links in the entire process. Furthermore, by improving data mining techniques, it can lead to a better implementation of knowledge management in the transport sector with data integration in the eras of the Digital Transformation, Big Data, Information and Communications Technologies (ICTs) and Internet of Things (Ahmed *et al.* 2017; Rusitschka, Curry 2016; Bąk, Borkowski 2015; Shemshadi *et al.* 2017).

This paper focuses on the development of an innovative three-step taxonomy framework that helps assessing and monitoring new transport technologies and trends. It aims to provide guidance to relevant stakeholders interested in transport Research and Innovation (R&I), such as policy makers, transport industry, investors, research organisations and the general user, by organising R&I activities in a coherent manner, thus providing support for future research and policy developments. After a brief introduction of challenges and the technology hype in the transport sector in Section 1, Section 2 provides an outline of the use of taxonomies and an introduction for the implementation of the propose taxonomy. Section 3 focuses on transport (R&I) policy support tools that can be combined with the proposed taxonomy framework. Sections 4 and 5 focus on the steps towards the taxonomy framework and the framework itself respectively. The last section provides conclusions, recommendations and challenges in the implementation of the proposed framework.

1. Characteristics of the transport sector and technology hype

The transport sector presents some unique characteristics. In principle, it is intrinsically a very dynamic sector, even though conventional transport modes are nowadays consolidated, with mostly evolutionary improvements for what regards their capacity, efficiency, safety, and reliability in the last years. However, transport is strongly linked to broad societal changes emerging from the ever-changing economies and the geopolitical situation: the global economic crisis, limited resources and new vulnerabilities and uncertainties have a direct impact on the way people and goods move. The presence of interaction loops (e.g. demand-offer) and the multiplicity of transport modes introduce dependencies within the process and are further complicated from new trending issues (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. Any change in a transport subsystem, even if predictable separately, can be difficult to predict or even counterintuitive, when considering the interactions, especially with the human agents (Sussman *et al.* 2009). Furthermore, transport technology is more than technical hardware. Even though it may often comprise mostly technical elements, the organisational innovations and new mobility concepts, which do not require hardware modifications can be also regarded as new technologies since they aim to use hardware in a different manner (Weber *et al.* 1999). In particular, new technologies and transport trends add new levels of interaction with the society and users and may have considerable influence on people mobility and freight transport services.

New technologies pass from different stages before their eventual acceptance and adoption by society. Existing technology adoption models help predict the adoption and diffusion of new technologies. Various standard adoption models have been proposed in the last decades, with a relevant one being the *Gartner Hype Cycle*. These models provide a more structured view on the development of the maturity of an emerging technology, through different phases, namely from technology trigger to mainstream adoption (Dedehayir, Steinert 2016; Gartner Inc. 2018). The *Gartner Hype Cycle* (curve) combines two attributes (hype level and engineering or business maturity) and adopts five key phases of a technology's life cycle: technology trigger, peak of inflated expectations, trough of disillusionment, slope of enlightenment and plateau of productivity. It is proposed as a structured, qualitative research tool, aided by expert judgement, focusing on three additional fields: the maturity level, the time to plateau and the market penetration (Fenn *et al.* 2013). As a recent example within the transport sector, after a period of initial excitement, autonomous vehicles were at the peak of inflated expectations in 2015. Likewise, drones (unmanned aerial vehicles) spanned the peak of inflated expectations in just one year, and in 2017, they were about to enter the trough of disillusionment. The Gartner curve comes as a complement to other standard curves that describe the evolution of technology over time. These curves include the performance "S-shaped" or logistic curve, which shows the cumulative performance growth for a technology (Navas, Cruz-Machado 2015), and the Rogers standard adoption curve (Rogers 2003), which describes how innovations and ideas are accepted and adopted. Even though the performance curve is consolidated practice in academia, policy and industry (Grübler 1998), the

Gartner curve is mostly a qualitative tool that incorporates implicitly other fields (specifically, maturity rating and market penetration).

Nevertheless, the adoption of a new technology is difficult and not always possible to predict using a technology adoption model. This is the case of the hydrogen hype in the automobile sector (Bakker 2010), which failed to meet expectations, and eventually paved the road for hybrid and electric vehicles. Other more revolutionising transport technologies and products, such as the Segway personal transporter simply did not meet hype and expectations (Kemper 2003). Figure 1 presents the Gartner Hype curve together with the classic performance "S" curve (depicting technology maturity) and the adoption curve.

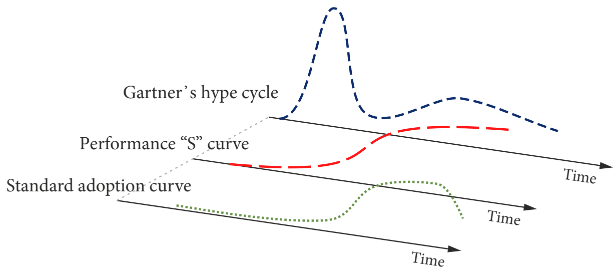

Figure 1. The *Gartner Hype Cycle*, performance "S" curve and standard adoption curve

Because of the above, it is important to assess the new transport technologies and trends and identify, since their early stages, those that are likely to have a high impact in the future "society-changing technologies". Such thing is possible only through the thorough knowledge of the technologies and trends, their components and their interdependencies (social, economic etc.). To this aim, the hierarchical structures deriving from the aforementioned taxonomic process need to be assessed through the appropriate grading system that will allow a more focused view of potentially successful trends and disruptions and their effect in other sectors. In Section 5.2, a taxonomy scoring system is proposed as an accompanying feature within the proposed framework.

To the authors' knowledge, the taxonomy framework proposed represents an absolute novelty for transport R&I analysis. Similar recent R&I monitoring state of the art activities, e.g. the European Commission's Tools for Innovation Monitoring (TIM), which allow users to extract knowledge and intelligence from datasets containing textual information (EC 2016b) are not based on a hierarchic taxonomy. The same is also true for the online TIM Energy used for mapping technologies and innovations in the field of energy as identified in the Strategic Energy Technologies Plan (SET-Plan) (EC 2015).

2. The use of taxonomies

Even though there is no univocal definition, a taxonomy is about the identification, tagging, classification, grouping and analysis of system parts. Generally, a taxonomy could be described as a process of defining the components of a specific domain. The background epistemology of each domain is the defining factor of the taxonomy's form and content, while each taxonomy's timeframe can be spanning between permanent, long lasting or even brief when used for the categorisation of specific research results (Smiraglia 2014).

The use of taxonomies to organise and describe complex systems is not new. Taxonomy started as a classification method for biological organisms and it has expanded in other fields, especially during the last decades. The history of biological taxonomy dates back to the 4th century BC and Aristotle (Gotthelf, Lennox 1987), who divided living things and organisms, in animals and plants. Many centuries later, the Linnaean taxonomy divided organisms in kingdoms (animal, vegetable and mineral), classes, orders, genera and species (Linnaeus 1758). The importance of the Linnaean taxonomy lies in the introduction of rankings and the simplification of representation and tagging. Albeit with further integrations, it enjoys today universal scientific acceptance. Evolutionary taxonomy, even though it has its origins in the 18th century, found new ground in the late 1960's (Mayr 1981). In this, the evolution of species is marked, having existing "species" giving rise to new groups, something inspired by and extending the Darwinian classification (Padian 1999). A special evolutionary taxonomy is provided by the phylogenetic or evolutionary tree as for example in O'Hara (1988) that represent evolutionary relationships between species or other groups and how they evolved from a series of common ancestors. An evolutionary tree provides a powerful way of representing evolution and at the same time can be enriched with additional information about the "species". One of the principal challenges is the taxonomy construction, including the topic hierarchy. The actual creation of a taxonomy is not trivial. Bailey (1994) provides a clustering analysis, fundamental for the construction of a taxonomy. Kashyap *et al.* (2005) provide a framework for the quality taxonomy extraction from the semantic web and the subsequent taxonomy labelling.

Taxonomies nowadays are used in many different sectors for organising both tangible and intangible elements. A series of important cases of taxonomic representation is provided below for the transport sector. The presented cases are not intended to be exhaustive, but rather to provide an indication on the multiplicity of applications. Crainic *et al.* (2018) provide a taxonomy of simulation in freight intermodal transport. Shaukat *et al.* (2018) provide a taxonomy of energy storage systems in Electric Vehicles. Fuest *et al.* (2018) present a taxonomy of traffic situations relevant to the assessment of communication processes between Automated Vehicles (AV) and other road users focusing not only on the interaction perspective of both AVs and drivers. Psaraftis and Kontovas (2013) present a survey of speed models in maritime transport, that is, models in which speed is one of the decision variables and provide a taxonomy after reviewing 40 publications on the topic. In accident investigation, the TRACEr (Technique for the Retrospective and predictive Analysis of Cognitive Errors) taxonomy has been developed for air and later ship accident investigations (Schröder-Hinrichs *et al.* 2013; Shorrock, Kirwan 2002). On the same topic (i.e. human errors), Stanton and Salmon (2009) provide a taxonomy of road transport error causing factors found in literature. SAE (2014) published the "Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles". In transport infrastructure, Sgambi *et al.* (2012) present a hierarchical taxonomy of the constituting elements of a long span suspension bridge. They use this taxonomy to facilitate the knowledge-based optimisation of the structural behaviour in the bridge design phase. The United States Department of Transportation (US DoT 2012) provides a taxonomy for Intelligent Transport Systems (ITS) applications. More recently, Katsumi and Fox (2018) present a survey of transport specific ontologies as a means of data elaboration for the support of knowledge management and reasoning, and within each of them, a taxonomy of transport related concepts.

Very recently, two efforts were made to identify and organise transport technologies in a taxonomy. The REFINET (2017) project identified a non-exhaustive collection (111 in total) of technologies in design, construction and maintenance of transport infrastructures from selected European research projects. Similarly, the INTEND (2018) project identified transport technologies from the 7th European Framework Programme (FP7) and the Horizon 2020 Framework Programme (H2020) projects, grouped into technology themes, across four transport modes. Although inspiration can be drawn, in both cases there are evident limitations. The taxonomy is represented in a static manner, sources are limited to a number of R&I projects, and there is no indication for future assessment linked to a database application.

In this context, the proposed taxonomy can be used in the assessment of new and emerging transport technologies and trends, linking with quantitative data (organised in a database) to assess different aspects of a system performance. In particular, the proposed framework can be potentially applied in order to:

- link with ancestors, i.e. earlier technologies, systems or components. In this way it is possible to:
  - mark the evolution and the relative performance variation;
  - check for previous fall-backs or failures;
  - learn from mistakes;
  - consider the specific socioeconomic timeframe for each period;
- assign interconnections with other sectors (e.g. technological, territorial, political, and psychology); also, identify the possible bottlenecks and drawbacks due to this interconnection;
- assign Key Performance Indicators (KPIs) for the introduction and acceptance of every component of the taxonomy, considering the status of its constituting elements;
- establish links with relevant stakeholders using appropriate criteria (geographical, sectorial, institutional, etc.) also for policy support.

The above can assist the establishment of a tool for the continuous, even real-time, assessment of the performance of new transport technologies and trends, as explained in detail in Section 5.2.

3. Transport technologies in R&I tools

An effort is taking place to assess quantitatively the R&I that takes place in the transport sector in the last years through various ongoing initiatives. To this aim, a number of tools have been developed worldwide covering research activity both at national and international level. Some tools have focused on stakeholder communication, dissemination and external involvement, while others have examined the data, reports or country profiles and analysed investments. Among the principal tools that include R&I databases on wide-ranging transport issues it is worth mentioning the Transport Research International Documentation (TRID–TRB) and the European Commission's Transport Research and Innovation Monitoring and Information System (TRIMIS):

- TRID–TRB is generally considered the world's largest and most comprehensive bibliographic resource on transport research information (National Academy of Sciences 2017). It combines the records from Transportation Research Board's (TRB) Transportation Research Information Services (TRIS) Database and the Organisation for Economic Cooperation and Development's (OECD) Joint Transport Research Centre's International Transport Research Documentation (ITRD) Database. Information include research projects, programmes (at international, national and state level) and articles;
- TRIMIS has been developed at the European Commision Joint Research Centre (JRC) 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 (EC 2017a). It is an open-access information and knowledge management system, and includes a database of transport projects and programmes, as well as an inventory of transport technologies and innovations. The audience of TRIMIS covers all transport stakeholders, ranging from policy makers to students, aiming at fulfilling their needs in terms of data acquisition and information gathering and dissemination.

The TRID–TRB and TRIMIS databases contain information that act as complementary to strictly scientific databases, including data on national and international R&I activities.

Other tools also try to meet the specific needs of transport R&I stakeholders. Figure 2 provides a chart with some principal sources i.e. R&I platforms (Tsakalidis *et al.* 2018a). The sources in the chart account for several aspects, including the availability of databases or the pub-

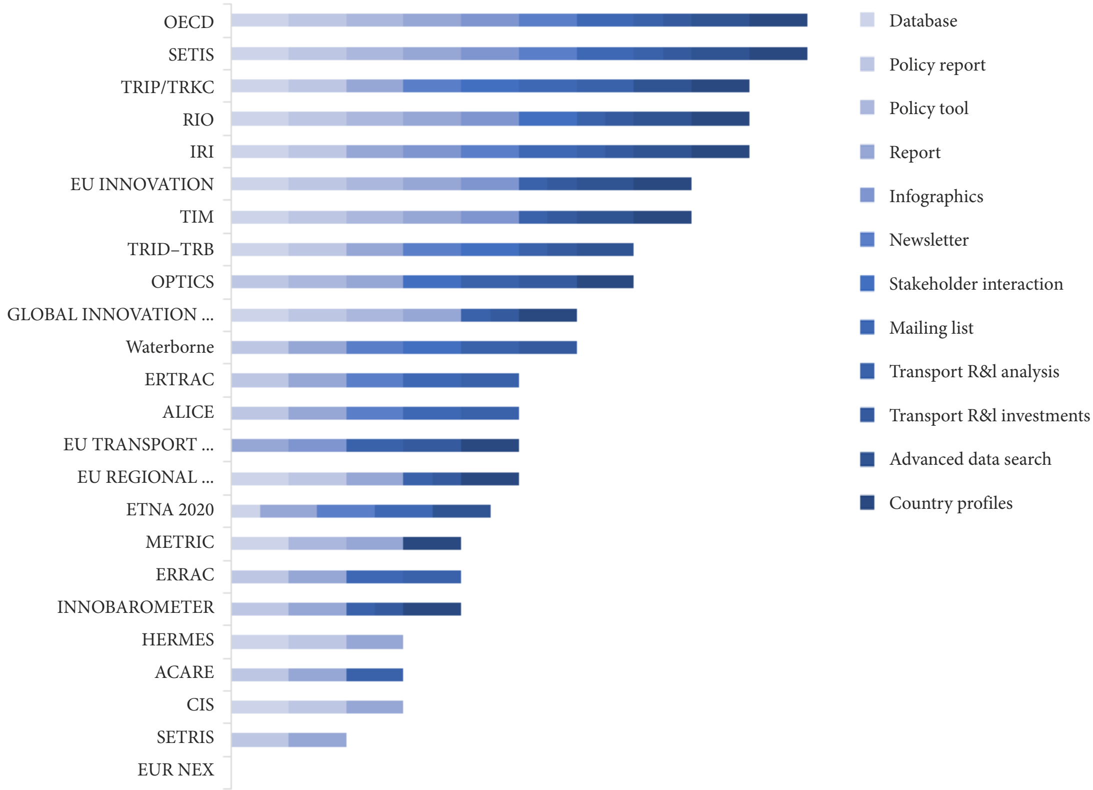

Figure 2. Principal R&I platforms and databases (Tsakalidis *et al.* 2018a)

lication of general reports. There are also few examples of tools that provide infographics, policy reports or country profiles. These include some European Commission tools, such as, the Economics of Industrial Research and Innovation (IRI) action (EC 2016a), the Research and Innovation Observatory (RIO) (EC 2017b), the Tools for Innovation Monitoring (TIM) (EC 2016b), the European Union Innovation Scoreboard, the European Union Transport Scoreboard (EC 2017c) and the SETIS tool (EC 2017d). A very relevant aspect that was taken into consideration is the possibility to access transport R&I analysis, a functionality currently present in few of the sources analysed, specifically the European Union Technology Platforms (EC 2016c): ACARE, ALICE, ERRAC, ERTRAC and Waterborne. Moreover, very few tools provide the possibility to access data through an advanced data search. Among international initiatives and beyond the TRIB–TRB tool (National Academy of Sciences 2017), it is worth mentioning the OECD website (OECD 2016).

Given the heterogeneous nature of such initiatives, very few are able to meet the needs of all stakeholders, since they are missing one or more key aspects that support R&I (e.g. transport R&I databases, policy reports, infographics, newsletters, interaction with stakeholders, transport R&I analysis, investment analysis, mailing list, data search and country profiles). Furthermore, many initiatives focus on public R&I while the assessment of private R&I investments is more complicated and requires additional analyses (Wiesenthal *et al.* 2015). Nevertheless, the above-mentioned resources of transport R&I can be used in the modelling of innovation stages using bibliometric analysis, something widely used as a practical tool to evaluate scientific activities (Yeo *et al.* 2015).

To the authors' knowledge, none of the existing tools provides a hierarchic taxonomy system approach as the one proposed in this paper for assessing transport R&I.

Nevertheless, the connection between those platforms and a taxonomy framework is bidirectional in the sense that on one hand they can provide data and information on a sector or specific domain and on the other hand the taxonomy framework can be a basis for their (re)organisation, initiating from the sectorial assessment. To this aim, a taxonomy can provide the breakdown of a technology in components, and the continuous updating, something essential for the bibliometric analysis.

4. Towards a taxonomy of new and emerging transport technologies and trends

In order to attain a taxonomy of new and emerging transport technologies and trends, it is important first to obtain a basic inventory. In building the inventory, a set of tasks is necessary that focus on the organisation of technologies according to their broadness, their classification and their assessment (Figure 3). The three sequential steps described above (technology categorisation, classification and assessment) provide the basis for building a taxonomy of transport technologies and trends.

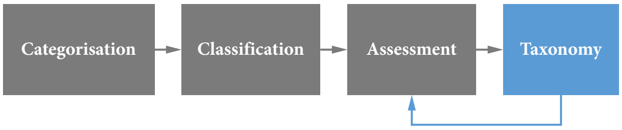

Figure 3. Stages of development for a taxonomy of new and emerging transport technologies and trends

After the taxonomy is developed, it will be possible to provide a continuous assessment of the technologies and trends and plan additional steps (e.g. policy support). The following sections provide an overview of the developed tasks.

4.1. Transport technologies and trends categorisation

New and emerging technologies and trends need to be organised and allocated to different categories.

Two principal categories can be considered at a top level:

- new transport modes, large-scale technologies, or disruptive technologies or trends;
- new or innovative technologies with influence on existing transport practice.

For example, an entire new mode of transport (e.g. hyperloop) will fall into the first category, while, a new battery technology for electric cars will fall into the second category.

Furthermore, a technology can either provide incremental changes or be radical and ground-breaking. In the above example, a hyperloop has the potential to be radical, while for a new battery technology, further considerations are needed (e.g. looking at the efficiency and comparing it current practice).

Subsequently, and considering the above examples, an assessment must take place to further assess the future effect of the technology or trend in terms of potential impact.

4.2. Technology classification

It is important to perform a classification of new and emerging transport technologies and trends focusing on their maturity level and their readiness for implementation. For some technologies, this is possible merely by looking at their Technology Readiness Level (TRL). The National Aeronautics and Space Administration (NASA) initially introduced readiness levels for space missions in the mid-70's, with reference to technology readiness, serving as a method of testing technology maturity (Mai 2012). Since then, the concept has been extended over the years to other fields with inherent risk, such as intellectual property, manufacturing, framework, systems integration, commercialisation, market, consumer and society. Different agencies and institutions adopt different definitions for TRLs. For instance, a full description of TRLs in the European Commission can be found in De Rose *et al.* (2017). TRL in particular can be used to categorise a technology as "new" or "emerging", as it has been done for the Future and Emerging Technologies (FETs) in the Low Carbon Energy Observatory (LCEO) – see for example Moro *et al.* (2017). FETs focus on high risk, long term, multidisciplinary and collaborative frontier research with a high potential impact on technology, to benefit our economy and society. The idea is to convert proofs of concept into industrial applications and systems. In general, FETs are new and emerging technologies characterised by low TRL, and eventually without well-defined societal impact.

4.3. Technology assessment

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

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 does not need to be based exclusively on strict socio-economic models, but it can be performed using other theories e.g. the Theory of Planned Behaviour by Ajzen (1991, 1985). It is also possible to model the effect of a new transport technology or trend on the basis of current practices and Technology Acceptance Models (see for example, Venkatesh *et al.* (2003)), with criteria based on:

- potential impact (from marginal to mode shift);
- social acceptance.

The assessment method is tailored to the specific level and the dependencies from lower levels are reflected. For example, a low readiness level in a component of a system may prove to be a bottleneck for the entire system.

5. A taxonomy of new and emerging transport technologies and trends

The taxonomy will enable the continuous updating of the technology assessment, through the calculation and continuous updating of a taxonomy index. The methodology follows the flow of Figure 4 and is developed in three sequential steps, comprising: the definition of the taxonomy domain, the development of the taxonomy scoring system and the taxonomy visualisation (taxonomy front–end).

5.1. The taxonomy domain definition

The taxonomy is developed in a database application, with the purpose to include all possible transport technologies and applications, using appropriate tags and using a hybrid top-down and bottom-up process (Figure 5). The concurrent database development will allow crosschecking instantly the relevance to different aspects. In the first phase of implementation, the taxonomy will follow a strict model, in the form of a hierarchical network diagram, in the sense provided in the original paper by Simon (1962).

In a second phase, additional visualisations will be considered (e.g. network type) that will allow highlighting the interconnections between technologies and transport aspects.

Figure 6 provides an overview of resources for the taxonomy bottom-up development that include both structured and unstructured text.

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

This subdivision allows organising 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:

- ***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;
- ***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;
- ***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.;
- ***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.

As stated before, the taxonomy elements can be both tangible and intangible, depending also on the scale.

Additional dimensions will be considered for the taxonomy, e.g. time. 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 straightforward, 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.

The taxonomy is completed with the definition and selection of a set of attributes for each element. Attributes include both performance measures and additional descriptions, and may include:

- readiness levels, e.g. TRL; depending on each individual element, other appropriate indicators can be considered (system or integration readiness levels, Manufacturing Readiness Levels (MRLs), market readiness levels);
- technology hype; this can be defined and measured in different ways, even though, as stated in Section 2, its quantification is not straightforward;
- socioeconomic and geographic aspects, e.g. relevance to specific areas and regions, including production and manufacturing aspects;

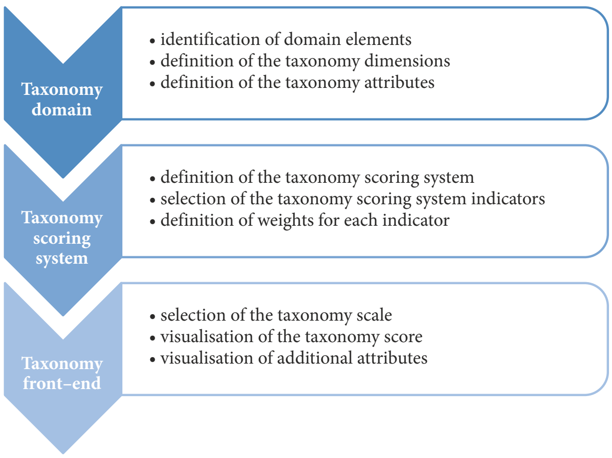

Figure 4. Methodologic steps of the taxonomy process

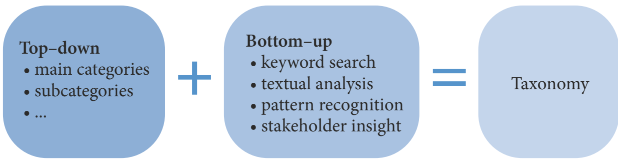

Figure 5. Taxonomy building hybrid process

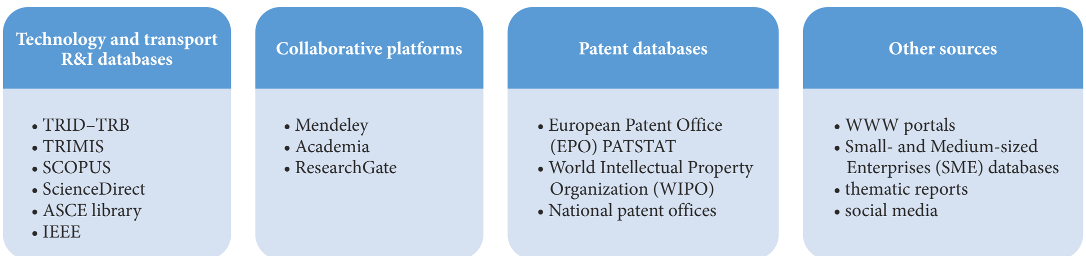

Figure 6. Overview of taxonomy building resources

- association with transport modes, policies (EC 2016d) and other classifications. For example, an additional possible classification of interest to the European Research Area could occur using the Strategic Research and Innovation Agenda (EC 2017e) adopted by the European Commission as part of the "Europe on the move" package, which has identified priority areas with specific actions for future R&I outlined in seven roadmaps.

Additional key performance indicators can be developed and associated to each element of the taxonomy. Furthermore, the taxonomy will also prove useful for future studies, for example, the identification of elements and parts for risk analyses (Haimes 2008).

5.2. The taxonomy scoring system

The proposed taxonomy will be used also for the continuous assessment of new and emerging technologies and trends. A methodology can be developed based on the following steps:

- association of each element at a given scale with a dynamic grade and a weight. The grade will be used as a comparison within elements at the same scale. For example, for an electric vehicle battery a grade will help assess the performance of different batteries according to defined performance criteria (cost, specific power, TRL, commercial availability etc.). On the other hand, the weight will help identify the relevance of the element to the superior level;
- dynamically computing the performance of the mega scale technology or trend as an outcome of the lower level constituting elements; this will be possible also by setting different boundaries (e.g. timeframe, geographical).

The authors propose a taxonomy scoring system, as a multidimensional scoring system that comprises different performance indicators at a given time instance. These indicators may at any given point be characterised by a temporal offset bound by the times of technology trigger and maturity or abandonment.

The Taxonomy Score (TS) to measure the performance of a taxonomy element within a specific domain can be calculated according to equation:

$$TS = \sum_{i=1}^{m} w_i \cdot a_i^t ,$$

where: t – time; w_i – weight of performance indicator i; a_i^t – value of the performance indicator i at a given time t.

Regarding the choice of the indicators, these come from corroborated literature and industry practice, and their selection will take place with criteria the availability of data or easiness of calculation. They will be followed by a validation phase in order to test their appropriateness. Candidate indicators include TRL, system readiness levels (Sauser *et al.* 2006), MRL and technology operation and functional performance metrics (Koh, Magee 2006). The possibility to adopt a quantitative measure of "hype" as an indicator will be considered, using for example bibliometric analysis on scientific publication and patent applications (Campani, Vaglio 2015) and internet traffic (Jun 2012).

Regarding the actual implementation, it is assumed that the values for each performance indicator are provided or calculated at any point of time, for both technologies and trends and their constituting parts (lower hierarchies in the taxonomy). This will require building up an automatic link to sources of information or the regular calculation and update of performance metrics. Some indicators (e.g. TRL, MRL) are presented in ordinal scale. For other indicators (e.g. bibliometric analysis, research budget) it will be necessary to normalise the nominal values.

The benefit of the proposed score is that, using a hierarchic taxonomy for each technology, it will be 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 will be possible to obtain a scoring 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.

5.3. The taxonomy "front–end"

This section focuses on the front–end interface of the proposed taxonomy framework. The results can be presented based on:

- the data stored in an n-dimensional matrix as presented in Section 5.1;
- the scoring system based on Section 5.2, which will be used for the assessment of technological status compared to either static thresholds or temporal comparisons.

Figure 7 focuses on a specific scale of the taxonomy (meso-scale) and is based on the on-going assessment-taking place within TRIMIS (EC 2017a). The TRIMIS database (Tsakalidis *et al.* 2018b) currently includes more than 7000 European and National (Member State) research projects. A high number of projects (1946 projects as of 12/2018) has been assessed from FP7 (2007–2013) and H2020 (2014-ongoing), for what regards:

- the technologies addressed (grouped in a hierarchic taxonomy as described in Section 5.1);
- their development phase (from research to implementation).

In total, 1110 technologies have been identified that represent the meso-scale in the taxonomy, linked to about 60 macro-scale elements (one-to-many representation). As of 12/2018 there are 1220 projects with either a TRL or a "development phase" assigned (a project may contain more than one technology). It was chosen to focus on the development phase since only a small fraction (roughly 10%) of the projects explicitly indicate a TRL. Table shows the number of technologies addressed and the corresponding development phase, linked to the TRL.

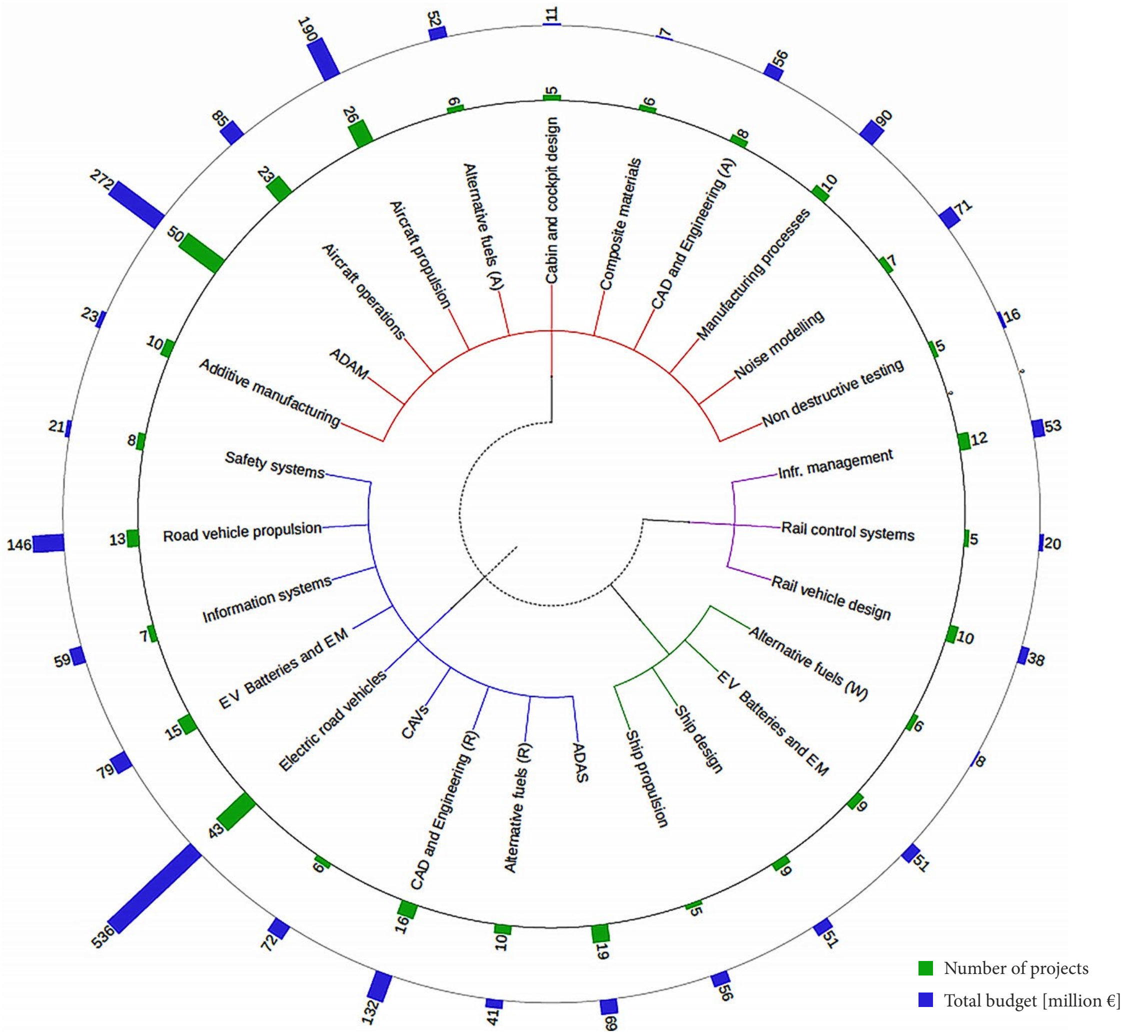

Figure 7. Extract of transport technologies developed under Framework Programmes (data as of 12/2018 subject to change): *colours*: blue – road; red – aviation; purple – rail; green – waterborne; *abbreviations:* (A in red) – aviation; (W in green) – waterborne; (R in blue) – road; ADAS – Advanced Driver Assistance Systems; EV – Electric Vehicles; EM – Energy Management; ADAM – Advanced Design And Manufacturing; CAD – Computer-Aided Design; CAVs – Connected and Automated Vehicles; Infr – infrastructure

Table. Technologies addressed within Framework Programmes (2007–2018)

Development phase	FP7 projects [No]	H2020 projects [No]
Research or Invention (TRL 1–2) and Validation (TRL 3–4)	565	469
Demonstration or Prototyping or Pilot Production (TRL 5–7)	49	54
Implementation (TRL 8–9)	30	53

The taxonomy "front–end" in the form of a "technology map" of Figure 7, links transport related technologies to European R&I projects and identifies those technology themes that are promising for further development. The figure, based on preliminary results from H2020 projects, shows that electric road vehicles are by far the most prominent theme across all transport modes. CAVs also appear among the top 5 funded themes in the road transport sector.

It is possible to visualise for the different elements of the taxonomy (outer part of the circular section), different attributes that may be part of the scoring system or even additional attributes that can provide information in a qualitative or quantitative manner. In the specific case, elements are grouped according to the different transport modes (road, aviation, rail and waterborne), and the attributes shown (starting from the outer part of the circular section) are:

- "Total budget" (blue colour in Figure 7);
- "Number of projects" (green colour in Figure 7).

A TS can be calculated by weighting the two previous attributes or considering additional attributes. For representation purposes, the number of technology fields has been filtered (to technologies addressed in 5 or more projects). The process, based on the proposed methodology, is on-going and continuous (since on average 30–50 projects are added every month in the database) and will be optimised for a web-interface representation.

The front–end interface representation is based on the open and freely available interactive tree of life (Letunic, Bork 2016) a web-based tool for the display, editing and annotation of phylogenetic trees. The process can be automatised and additional representations can be implemented, showing lower and higher levels of the taxonomy and different attributes. The opportunity to develop dedicated tools or create a web-based tool for the representation of outcomes will be considered.

Discussion and conclusions

This paper provides a methodological framework for the creation of a taxonomy for new and emerging transport technologies and trends. A set of implementation methods for the aforementioned taxonomy is outlined aiming at the assessment and the monitoring of transport technologies and trends. In particular, a methodology is provided for using this framework for the quantitative assessment of the attractiveness and competitiveness (also in terms of diffusion potential) of emerging transport technologies and trends associating explicit indices (e.g. TRL levels or technology development phases) to the different elements of the taxonomies.

The principal novelty of the proposed framework is that, since the taxonomy is organised within a database, it is open to additional development for both policy and research. Using the taxonomy allows to explore interconnections with other sectors linked to transport (e.g. technological, territorial, political, and psychology), identifying possible bottlenecks and drawbacks. In addition, by assigning pertinent attributes (KPIs) to each element of a certain scale, it is possible to assess the performance of the elements or parts in the superior scale. Finally, it is possible to focus only on aspects of interest (geographical, sectorial, institutional, etc.), something useful in policy support.

There are a number of challenges in implementing this methodology. The availability of up-to-date performance data for parts of the technology is essential and an eventual lack of them could delay the whole process. More specifically, the authors applied this methodology on a dataset from the European Commission's TRIMIS, which was updated and enhanced only in the second half of 2018 with data regarding European and national R&I funding. Thus, the quality of the dataset was a bottleneck for the application of the methodology. The next steps are to include in the analyses patent and bibliographic data, using respectively data from EPO Worldwide Patent Statistical Database (PATSTAT) and the SCOPUS database. A challenge arises from linking the taxonomy with patent codes and research keywords, something that will be addressed using semantic analyses. Consequently, these performance indicators will be included in the taxonomy score. The example taxonomy front–end presented in Section 5.3 will need to be integrated and optimised for a web-interface, that includes a user-friendly selection of the different levels of the taxonomy, together with filtering (geographic, temporal, mode specific).

The proposed three-step taxonomy framework provides support to the identification and assessment of new and emerging technologies and trends in the field of transport at various scales, thus providing insights to the sector's stakeholders, while backing the current transport systems' transformation through technological advances. To the authors' knowledge this is a first time that transport R&I analysis is backed by such system approach.

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Disclosure statement

The authors declare that they do not have any competing financial, professional, or personal interests from other parties.

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