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Transport research implementation: current issues and lessons learned from Europe and China

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The implementation of the research results is seen as a crucial step in the development of innovation in the transport sector. Moving to such an implementation is not always easy or straightforward. It requires a suitable organizational framework both inside as well as outside research producing entities and a number of other facilitating factors that are usually found within an innovation ecosystem. The paper examines systematically the conditions and prevailing practices for transport research implementation in Europe (the European Union) and China and draws useful insights as to the factors that influence such implementation, the incentives, and other facilitating provisions that the research funding organizations can take. It also analyses the current practice and lessons learned for research implementation on the road to innovation production in four major areas of transport research namely: Automated Mobility, Intelligent Railways, Shared and Micromobility applications, and Electromobility.

KEYWORDS

transport research, research implementation, innovation, autonomous mobility, intelligent railways, micro mobility, automated vehicles

1 Introduction

One of the earliest definitions of *innovation* is the one given by Joseph Schumpeter[1] as: “*Innovation is the commercial exploitation of new ideas*” (Schumpeter, 2014). Today, we know that although Schumpeter’s definition is basically correct, the complex and multifaceted nature of innovation—especially in the transport sector—requires a deeper expression of the processes of innovation that take place over time and location. A recent definition of innovation in the transport sector (which was an innovation), is given in a book by Giannopoulos and Munro and according to this, innovation is the creation of commercially attractive new products or services based on scientific research and analysis and materializing through the existence of “innovation ecosystems”. The same book defines as innovation ecosystem all active organizations that are interacting to fulfil innovation related activities within a specific field and, typically, are located within a geographically proximate area, or are interacting virtually (Giannopoulos and

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[1] Economist and one of the 20th century’s greatest intellectuals.

TABLE 1 The parallelism of biological and innovation ecosystems.

Common features	Expression in natural or biological ecosystems	Expression in innovation ecosystems
Use of networks i.e., relationships with other ecosystems or individual entities	Relations with other species (e.g., relationship between flowering plants and animal pollinators such as bees)	Relations with third parties (e.g., the relationship between the auto manufacturing sector and the Original Equipment Manufacturers - OEMs sector in automobile manufacturing
Existence of *distinct - discernable boundaries* that define the ecosystem's limit	All living organisms in a natural or biological ecosystem are within a contiguous geographic location. Within this location there are also abiotic elements that connect the biological ecosystem to the inanimate physical environment	Innovation ecosystems include all active organizations that are involved in similar or related innovation activities typically within a geographically proximate area
Reliance on "champions" to move the ecosystem forward	Biological "actors" with specific attributes and "operational codes" (e.g., animals at the top of the "food chain", or dominant plants that perform key services (roles) within the ecosystem, including helping to prune the non-competitive elements of the ecosystem)	Leading organizational entities within an innovation ecosystem such as large universities, major technology transfer entities, key industrial or manufacturing entities
Ability to regulate change and maintain an equilibrium state	An equilibrium state in a natural or biological ecosystem is maintained through energy dynamics in the form of inputs (e.g., sunlight and key nutrients), and outputs (e.g., genetic resources, food and fiber, cleaner air, fresh water, etc.)	Innovation ecosystems stay also in equilibrium and viability via a series of inputs from interacting stakeholders, e.g., venture capitalists, banks, or government investment. When they fail to generate sufficient input capital (most notably through Initial Public Offerings—IPOs), venture capitalists typically reduce their investments in new companies and innovations within the ecosystem and refocus their attention on other investments. Then equilibrium is lost, and innovation ecosystems decline very much like biological ecosystems do when the influx of light or nutrients decline
Diversity, resilience, and heterogeneity are a necessary condition for success	These attributes define the "health" of a natural or biological ecosystem. The greater the heterogeneity, the more adaptable the ecosystem is to changing external (environmental or other) conditions. The severity of the environment influences the overall heterogeneity and richness of the ecosystem and causes it to have fewer species and an overall decline in its "health"	In innovation ecosystems where significant reductions in the number of active competitors develop, due to various conditions external or internal, competition, diversity, resilience and heterogeneity of the system is reduced, and this impacts the very stability and "health" of the ecosystem. Where there is robust competition, innovation thrives. The opposite condition is in cases where there is dominance of few firms (monopolistic situations), general economic decline, etc.
Existence of a "*metabolism*" function	In biological ecosystems "metabolism" refers to the total energy processed by the individual organisms that comprise the ecosystem	In an innovation ecosystem "metabolism" represents the total amount of investment capital that is processed (consumed) by innovators to produce innovations or buy promising start-up firms and so on. The ratio of capital to innovation production and profit is an initial measure of the *productive efficiency* of the innovation ecosystem
Validity of the "*Interconnectivity principle*". (The existence of a number of critical linkages, or interconnections, established between major components of the ecosystem over time)	All biological or natural ecosystems abide by this principle whose simplest and most visible form is the food chain pyramid in which one stratum of elements is providing nutrients and food to the next up, level in the (food) hierarchy Internal or external "predators" (animals at the top of the "food chain") perform key services in helping to prune the "non-competitive" elements of the natural or biological ecosystem	The interconnectivity principle is also valid in an innovation ecosystem where its sustainability and productivity depend on its ability to creatively connect and respond to external entities, conditions, or perturbations The role of "predators" can also be found in innovation ecosystems in the usually large entities that gradually rule and dominate the system in a political, economic, technological, or social context
Development and maintenance of *mutualistic* relationships (Substantial functions of the ecosystem depend on external or internal elements on a mutually beneficial way)	The classic mutualistic relationship in natural ecosystems is between flowering plants and animal pollinators such as bees. Both plants and animals need each other to survive	In an innovation ecosystem, innovators often use the services of third parties in a mutualistic relationship. For example, the auto manufacturers use the services of the Original Equipment Manufacturers - OEMs and in some cases their production fully depends on them and *vice versa*. Another mutualistic relationship is the relationship between the corporate innovator and its lead scientists and engineers

Munro, 2019). Most of the transportation innovatory processes and technologies that we use today are rooted in scientific research and theoretical advances in the transportation field in earlier years. So, transport research implementation plays a fundamental role in innovation creation.

Transportation research does not always involve discoveries that lead directly or immediately to commercial exploitation, nor does its implementation follow a linear path to innovation. It usually follows a rather disjointed pathway that embodies complexity, heterogeneity, and uncertainty while at the same time relies mostly on private funding (usually by large industrial companies) eager to bring to the market innovatory products and services (Carleton, 2013). The term "implementation of research results" in the transport field, is used to denote the taking of all necessary steps and actions to commercialize and further exploit the results from a specific research project mainly by putting them to practical use irrespective of the type of research products from the more material (technological and infrastructural) to the more intangible (managerial and organizational. "Innovation", differs from "research implementation" in that it presumes market induced commercial exploitation of research products i.e. a level of exploitation greater than simply the dissemination and simple application of research results. Government involvement in transport research implementation is normally in response to supporting policy objectives and perceived social or security interests or to change the current transportation *status quo* in a region or country or sector. Any research implementation activity takes place within a wider system of innovation production, the innovation ecosystem, which involves existence of an organizational system (legislation, organizations that are active and act as innovation agents, etc.), and sufficient funding sources.

The existence and function of an innovation "ecosystem" was very successfully paralleled to a biological or natural ecosystem. In Table 1, we give in a simplified form some of the most striking resemblances of biological and innovation ecosystems. The analogy is used mainly for demonstration and better understanding of what an "innovation ecosystem" is and how it can be modelled as a dynamic and interdependent network of elements. Table 1 includes some elements and ideas first described in (Giannopoulos and Munro, 2019, Ch. 2).

A critical element in understanding the processes of innovation production is the understanding of the enabling factors and procedures through which the results of research are implemented (Ardito et al., 2015; Nimawat and Gidwani, 2023). Such procedures differ from region to region and from country to country as they are largely dependent on the cognitive and political environment that exists and the nature, magnitude, and sensitivity of the respective innovation ecosystems (Giada Cannas et al., 2020). It is therefore of great interest to examine the governance processes as well as the operational conditions that exist in different countries as regards the process of production of innovation in different countries. Two of the leading areas in terms of transport research production and implementation in the world, today, are the European Union (EU) with its 27 member countries, and China. As it was shown in previous publications by one of the authors, China together with Japan, and S. Korea are currently developing to become the area with the highest level of transport research performance worldwide both in terms of quantity and diversity of the research as well as its quality (Giannopoulos ed, 2018; Giannopoulos et al., 2021).

Our objective, in this paper, is to demonstrate, by using appropriate "case studies" or paradigms, first the existence and operation of transport innovation ecosystems and secondly the role that transport research has played in their successful outcomes. We call these case studies "paradigms" by reference to the definition of a "paradigm" given by T.S. Kuhn, "*paradigms are sets of shared beliefs about cause-and-effect relationships and standards of practice that guide the research of entire scientific communities*" (Kuhn, 1962). This paper aims to present, analyze, and discuss the main features and elements of the research implementation and, even further, of the innovation creation landscapes in two research and innovation leading regions of the world, namely the European Union (EU) and China. These two regions are selected because of the multitude of cases for transport research implementation that can be found in their territories and the innovatory nature of their research and innovation ecosystems. Furthermore, the authors, having worked for all their professional lives in these two regions, can submit their own experience and lessons learned which can surely be of interest to the reader. In addition, the existence in these two regions of two different national as well as research governance models adds to the interest of examining the procedures and success or failure cases that apply and influence transport research implementation in each case.

The research questions, to which this paper will try to reply, can be formulated as follows: How is the notion of "innovation ecosystem" materialized in two major economic regions of the world (EU and China)? What is the current picture as regards innovation creation and implementation of transport research in these two regions (examination of four major transport innovation cases)? What can be done to better utilize the results from transport research projects and to increase their impact on innovation?

2 Overview of the transport innovation ecosystem landscape in the European Union and China

2.1 European Union countries

In the EU the quest for implementation of transport research results started relatively late and mainly for publicly funded research (European Commission, 2011; European Commission, 2012). In 2014, the Directorate General for Research and Technological Development (DG RTD) of the European Commission in collaboration with the Office of the Assistant Secretary for Research and Technology of the U.S. Department of Transportation organized, in Paris—France, a 2-day workshop on transport research results implementation with a select participation of relevant stakeholders (TRB, 2015). The findings of that workshop in terms of the main factors affecting the implementation of transport research, formed a basis for further discussion in subsequent years and constitute a good list of "lessons learned". The reference to the US transport research implementation experience that we make below and, occasionally in other parts of the paper, is basically extemporaneous but since the US and the EU practices in this field are quite similar the US references add to the validity of the argumentation of the paper and its attempt to answer the research questions. The results of the 2014 Paris workshop can be summarized in the following eight points (TRB, 2015):

1. *Stakeholder involvement.* Key stakeholders should be involved early in the research process and then continuously until its implementation planning.
2. *Post research, technology maturity.* Following the completion of a transport research project, the resulting new technologies are often not ready for the market. They need pilot testing, certification, and other prerequisites in order for them to “mature” and get “market ready”. Committing resources for such post-research implementation activities should be promoted more rigorously in the future. In the US Strategic Highway Research Program no. 2 (SHRP 2), such provision is already being inserted in the research contracts as a possibility.
3. *Early adopters and champions* are very valuable in getting the word for new products out early and supporting research implementation activities and generally helping to catalyze research result adoption.
4. *Overcoming institutional barriers.* Usually, multiple layers of approval procedures, standards as well as procurement rules and regulations, come into play before a research result can be implemented. These procedures must be simplified as much as possible and administrative hurdles overcome.
5. *Government leadership.* Government leadership can be a valuable catalyst for change, that accelerates innovation. For example, the *Everyday Counts* (EDC) program of the US Federal Highway Administration—now in its 7th edition[2]—has for 10 years now helped in rapidly deploying proven technologies and processes that resulted from transport research to promote innovation.
6. *Communication.* Communication of research results to the external world but also internally (i.e., within the research performing entities), could create a *pull factor* that generates demand and plant the seeds of implementation.
7. *Market readiness.* Parallel to the promotion of new innovative products and services to the market, also the market should be prepared for the innovations to come. Such “preparation” may involve undertaking information and publicity campaigns as well as discussions and workshops. The aim is to prepare the “soil”, so to speak, for the “seeds” of research to grow.

An earlier study, by the *Institute for Prospective Technological Studies* (IPTS) of the European Commission’s Joint Research Centre had investigated the data and issues involved in innovation creation by the private sector in the European transport sector (Wiesenthal et al., 2011). This is perhaps the most comprehensive study, so far, of innovation creation in the transport sector in Europe and, though it is now more than 10 years old its main findings are still valid and worth noting. According to this study, road transport innovation is by far the most extensive and widespread area of innovation in the transport sector having followed a long and evolutionary process that started before the 1990s. It has concentrated mainly around the following seven application areas: traveller information, traffic management, electronic pricing and payment, freight and logistics, vehicle safety systems, co-operative systems, and Information/Communication (ICT) infrastructures.

The innovatory products that resulted from publicly and (mainly) privately funded road transport research in the 90’s and 00’s are many and well-established today. Examples include the so-called *Intelligent Car* initiative (one of the key research streams of the 90’s) aimed at finding common solutions to Europe’s urban mobility problems and to improve the take-up of ICT in road transport especially for road safety issues (European Commission, 2006). Another example is the *EasyWay* initiative of the 90’s, a research project-driven set of research results and innovations aimed to facilitate road traffic in the main European international motorway corridors—the so called Trans-European-Network (road) corridors. The *EasyWay* initiative focused on four priority areas: a) optimal use of road traffic and travel data (innovatory products were: the *ecall*, the Traffic Message Channel—TMC, the relay of safety-related traffic information, truck parking information transmission and others); b) integration of Intelligent Transport Services (ITS) for traffic and freight management; c) ITS for safety and security; and d) integration of vehicles and infrastructures (a prelude to the current V2I communication systems). The *Easy Way* initiative resulted in today’s *2030 Digital decade* initiative of the European Commission (https://digital-strategy.ec.europa.eu/en). *Electronic Toll Collection* is another example of innovatory products that resulted from transport research in the 90’s.

In the waterborne transportation sector, innovation is mainly focused on the shipbuilding industry where European shipbuilders are today global leaders in the construction of complex vessels, including cruise ships, luxury yachts and offshore vessels. Also, the marine equipment sector has produced a wide range of research products ranging from propulsion systems, large diesel engines, environmental and safety systems to cargo handling and electronics.

In the railways, the main actors involved in rail-related research and innovation include infrastructure managers, urban transport operators and rail operators, the manufacturing and construction industries, as well as companies involved in rail related ICT activities. The main research effort is concentrated in locomotive/rolling stock and rail control systems (performed by such rail systems manufacturers or by the national railway authorities responsible for the rolling stock and the infrastructures). Perhaps the most well-known and internationally promoted innovation that came out of European rail related research, is the *European Rail Traffic Management System—ERTMS.* This is the current state-of-the-art system for rail traffic management and control whose elements were developed by eight European rail related industries (Alstom Transport, Ansaldo STS, AZD Praha, Bombardier Transportation, Invensys Rail, Mermec, Siemens Mobility, and Thales) with the active support of the European Commission. It consists of European Train Control System or ETCS that control the movement of the rail vehicles on the tracks and the *Global System for Mobile Communications—Railway* or GSM-R for the voice and data communication between all elements involved in the rail vehicle circulation and traffic monitoring.

The air transport sector is traditionally a high technology industry with an extensive research funding program by the EU

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[2] See https://www.fhwa.dot.gov/innovation/everydaycounts/

and national governments. In the context of the European transport industry, research funding comes second to the funding for new cars and road vehicles by the car manufacturers (Wiesenthal et al., 2011). The focus is on new engines and aircraft manufacturing materials but also a strong emphasis on air transport safety where many innovations are coming from air transport research funded by the EU or national governments. A flagship research and implementation program in the aviation sector is the research program SESAR (Single European Sky) co-funded by the European Commission. SESAR aims to improve air traffic management (ATM) performance by modernising and harmonizing ATM systems through the definition, development, validation and deployment of innovative technological and operational solutions. It has produced numerous research implementation actions as well as innovations. It is also to be noted that a substantial part of air transport innovation comes from implementation of military industry related research i.e., for military applications (Brandes and Poel, 2009).

An interesting overview of European transport technology and a proposed taxonomy and assessment as well as monitoring framework for innovation management in the field of transport, was published in 2019 whose two authors were involved in the European Union's *Transport Research and Innovation Monitoring and Information System—TRIMIS* (https://trimis.ec.europa.eu/). This work provides good insights to the European transport sector's stakeholders, while also considering the transport sector's interconnection with other sectors in producing innovation with reference to potentially related bottlenecks and drawbacks (Gkoumas and Tsakalidis, 2019).

As an overall realization one can see that the European transport sector innovation system comprises of many heterogeneous subsectors (modes, markets, service providers, vehicle manufacturers, cross-modal actors, construction companies building and maintaining infrastructure, etc.), all of which are exposed to a different market and innovation ecosystem environment. In this frame, the EU-funded Transport research program, through its funding represents a relatively small percentage of the total transport research funding in Europe of the order of 6%–7% as derived by data found in (TRIMIS, 2023). However, it seems to be defining the agenda for many national programs and guides the overall research and innovation policies followed (Stepniak et al., 2022). The principal Directorate Generals or DGs in the European Commission that are involved in Transport research are the DG RTD&I (Research Development and Innovation) and DG MOVE (Mobility and Transport). The EC is assisted in its role as funder of Transport research by several special bodies that advise it on matters of strategic planning, as well as of programming and monitoring. Principal among these bodies, are the four *European Technology Platforms* (ETPs) i.e., the *European Road Transport Research Advisory Committee* (ERTRAC)[3], the *European Rail Research Advisory Committee* (ERRAC)[4], the *Advisory Council for Aviation Research and innovation* in Europe (ACARE)[5] and the *European research and innovation platform for waterborne industries—WATERBORNE*[6] for maritime research. The Transport research and innovation production system of the EU is unique in the world. It is both independently driven—mainly by the relevant sector policies that are guided by "Strategic Research Agendas"—and at the same time it respects and accommodates the national priorities and interests of EU member countries.

2.2 China

Starting in the 90's, the Chinese government and its policies have emphasized the importance of research and the creation of innovation for economic growth and technological development. In more recent years the creation of innovation through research and technological development has been a key part of each 5-year plan that was established (Giannopoulos et al., 2018). By 2030, China expects to have technologically surpassed all economically advanced countries based on the creation of innovation. The term used in China for "innovation" is "*Transformation of scientific and technological achievements*". The Chinese national system for the creation and transformation of scientific and technological achievements displays all the basic elements that form the backbone of such systems in the rest of the world, i.e.:

a. *Government-led (public sector) innovation* through setting the policies and legislative frames to support innovation and through rigorous financing of post research implementation and innovation actions.
b. *Enterprise-led (private sector) innovation* led by independent (private or public) enterprises who finance and drive the product or processes innovation circle (market development, exploitation of resources, supply chain control for the necessary raw materials, organization and management of innovation).
c. *Scientific research in Institutes and Colleges or Universities* who are increasingly incentivized to produce inventions and patents for their research products.
d. Existence of *innovation intermediary entities* such as incubators, startup accelerators, research institution spin-off companies, as well as scientific and technological service agencies that are set up in compliance with the applying laws and regulations to promote technology transfer, transformation, and development.
e. Existence of *financial institutions that support innovation.* Banks and other financing facilities (such as venture capitals or even crowdsource funding) are available for research and innovation financing.

The difference with other countries lies on the degree of interdependence between the various elements of the innovation system and the strength of central governmental involvement in the whole process. A research-performing entity (such as individual researchers through start-up companies, or research institutes, or

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[3] See: http://www.ertrac.org/ (accessed June 2018).

[4] See: http://www.errac.org/ (accessed June 2018).

[5] See: http://www.acare4europe.org/ (accessed May 2018).

[6] See: https://www.waterborne.eu/ (accessed June 2018).

University research centers, etc.) can take the initiative to either directly produce by itself (perhaps also interacting with others) to promote a specific innovation or use specialized agencies as intermediaries. Cooperation and interdependence of innovation stakeholders as well as creation of viable innovation ecosystems, is facilitated through two main mechanisms supported by the national and regional or local governments in China:

A. "*Public technology service platforms*". These are web-based platforms constructed by national or local governments to support the direct (or indirect) interaction between innovation related "actors" within the technology market development system. The aim of these platforms is to facilitate the interaction between the research providers with the intermediaries or other innovation stakeholders within the innovation ecosystem. An example of such platform is the Ningbo Science and Technology service platform (http://www.nbjssc.org.cn) supported by the Ningbo municipality but there are many others.
B. The *Chinese Collaborative Innovation Centre Program* (CCICP). This is a national technological development program initiated by the State Council of the People's Republic of China aiming particularly to enhance the innovation capability of higher education institutions. The CCICP is jointly implemented by the Chinese Ministry of Education and the Ministry of Finance and was officially launched at national level in May 2012. Today, more than 30 national-level collaborative innovation centres exist in a corresponding number of universities and many more at provincial and municipality levels. Transport research is considered as one of the key tasks in the CCICPs. One of the first such centres, at national level, is the *Center for Coordinated Innovation of Rail Transport Safety* led by the Beijing Jiaotong University. Examples of other collaborative innovation centres devoted to Transport research, at provincial and municipal level, are the *Modern Urban Transportation Technology Collaboration and Innovation Centre* at the Southeast University in Nanjing established by the provincial government of Jiangsu; the *Ningbo Transport Co-operation and Innovation Centre* established by the municipal government of Ningbo; and the *Centre for Intelligent New Energy Vehicle* led by the Tongji University in Shanghai.

The promotion of the creation of innovation is facilitated in China through the formation and application of several (mainly) government led and supported "tools" and policies as well as financing. All these constitute the *Cooperative Transformation Mode for innovation* in China. The main elements of this landscape, are:

a. *Technology Alliances* i.e., alliances between innovatory enterprises or between them and other "actors". Through such cooperation the partners share the costs and responsibilities of the development work that is necessary to produce innovatory products and share the complementary benefits.
b. *Enterprise incubators* which provide the buildings and other infrastructures for start-up companies under a specific contract. A similar but lighter type of incubation used are the so-called "*shared innovation workshops*" of which there exist more than 3000 through the country. China is perhaps the country with the highest number of incubators in the world.
c. Government *innovation funding for private sector innovation.* This is a governmental fund aimed to support innovation in Small and Medium sized Technological Enterprises which operates in accordance with market economy rules to attract investment from local governments, enterprises, venture capitals and other financial institutions. It is intended to gradually promote the establishment of other larger mechanisms of investment in high-tech industries in accordance with the market economy rules. Established SMEs are funded to the amounts of 150—400,000 RMB ($20,000—45,000) by local governments, and 500,000–1,000,000 RMB ($95,000—170,000) by the central government. Start-ups are funded by slightly lower amounts. The same enterprises can also apply for National discounted loans.
d. *Special fund for the development of small and medium enterprises.* According to the "People's Republic of China SME Promotion Law", sponsored by the Chinese National Development and Reform Commission, the State Ministry of Industry and Information, and the Ministry of Finance, the central government's budget provides special funds to support small and medium sized enterprises for their specialization, their cooperation with large enterprises, and their "technological advancement and improving the development environment for small and medium-sized enterprises". There are various types of financial support that this fund can take, e.g.: Fixed assets construction fund; guarantee programs subsidy; enterprise quality elevation activity subsidy; or subsidies for Expo Central China.
e. *Private sector innovation funding.* All types of private sector innovation funding opportunities, known globally, also exist in China. They include:

i. *Angel funding*, aimed at supporting (mentoring and financing) young students and entrepreneurs to start a new innovatory action. Angel investment is an equity capital investment mode that is practiced by wealthy individuals who make a one-off upfront investment to original projects or small start-up enterprises with special technologies or unique concepts. Angel funds are established by the Chinese Angel Investment Network (https://www.investmentnetwork.cn/).
ii. *Venture capital funding* markets are well developed in China investing more than 700 billion RMB ($110 billion) every year to finance new start-ups and other innovatory companies. Chinese and foreign venture capitals such as IDG capital, Sequoia, Jingwei, Softbank China, etc., are some of the top names.
iii. *Crowdfunding* is also practiced in China quickly becoming one of the main sources of funding for innovation in small and medium sized enterprises. As of December 2022, there were more than 400 internet crowd-funding platforms raising some 3 billion RMB per year.

3 Transport research implementation within a transport innovation ecosystem

3.1 The research performing entity

Transport research takes place within research organizations such as universities, research centers, or private entities (consulting, or industrial) that have a vested interest in doing such research. All this research effort is performed under a contract with the financing organization. This contract describes the type of research to be done, its objectives, the methodology, the time scales involved, and the expected deliverables. After fulfilment of the provisions of the contract the research part is usually considered as completed and it is up to the performing organization to consider its continuation towards implementation of the results and innovative products. So, performing transport research represents the first stage of an innovation production cycle which will then be succeeded by other stages in the wider innovation ecosystem within which the research performing organization operates. Towards the conclusion of the research stage, or soon after it, the research performing entity will determine to pursue, or not, the exploitation of the results of its research either by itself or in collaboration with other entities (usually partners of the collaborative research consortium with which it cooperated in the research contract).

Some research work, and a recent survey among transport research performing entities at European level, have investigated the factors that influence and the conditions under which, decisions for the implementation and exploitation of research results are made in the context of collaborative IT-related research projects in the Transport sector (Doukidis, ed, 2019; Spanos et al., 2015; Kostopoulos et al., 2019). According to the findings of this analysis, the decision to continue and attempt implementation of research results depends on three categories of factors relating to the type of organization, the type of research project, and the context of the research done. These categories are further explained below:

A. "Type of organization":
  o The potential of the organization to assimilate "knowledge" and its ability to absorb and exploit this knowledge (*Knowledge assimilation, absorptive capacity,* and *exploitation potential*).
  o The *size* of the organization (in terms of turnover and/or number of employees).
  o The *familiarity* of the organization with other consortium partners or other entities in the innovation ecosystem and its legacy concerning past collaborations and innovation experience.
B. "Type of research project":
  o The *size* of the research project in terms of its budget and/or size of the consortium.
  o The type of research contract and type of the funding organization (public or private).
C. "Research -context":
  o The *relevance* of the technology or process that was discovered with the market demands or the technologies and processes most prevalent in the existing innovation ecosystem.
  o The *costs* associated with the promotion/post-research testing/customization of the new technology/system.
  o The *standardization* requirements that may be required (adaptation to existing or creation of new standards).

3.2 The funding and supervising entity

From the funding and supervising entity's point, the main question regarding the potential implementation of the research to be funded, is what are the provisions that must be put in the research contract to further assist and even incentivize the implementation of the results of this research or whether it should consider issuing calls for proposals for post-research implementation projects. Also, at which stage of the research should it "intervene" to "push" the research entities to consider implementation. Answering this question takes increased significance when the research funding comes from public funds and the supervising and funding authority is a public entity. Having extensive experience on such publicly funded research projects in Europe and China, the authors have formulated the following suggestions in Table 2 and these answer the questions posed here above.

3.3 Advocacy coalitions and the use of paradigms

Advocacy coalitions are "*coalitions of people from a variety of positions and professional backgrounds who share a particular belief system and who show a non-trivial degree of coordinated activity over time*" (Gabehart et al., 2022). Such coalitions of people favoring or opposing an innovation can have a substantially positive or negative impact on the final user acceptance of an innovation and can influence the role and intervention of the government in supporting it. The advocacy coalition in favor of decarbonization of the transport sector as a mean to combat climate change and the advocacy coalition in favor of the internal combustion engines and the do-nothing option (refusing to accept there is a climate change), is a good example of what advocacy coalitions do and can do. As it was suggested in item 32 of Table 2, generating, or supporting an advocacy coalition in favor of a new technology or other innovatory measure can provide considerable support for post-project implementation actions and can exercise positive influence to shape the surrounding environment to support the implementation of research results in a specific technological or operational area.

A *paradigm* is a past, current, or perspective set of ideas that formulate the way of looking at something. According to the Cambridge Dictionary, a *paradigm* is a "*set of theories that explain the way a particular subject is understood at a particular time*"[7]. The original meaning of the Greek word "paradigm" is, simply, an "example". Advocacy coalitions are usually connected to a certain paradigm and use it as the focus and center of their advocacy.

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[7] See, https://dictionary.cambridge.org/dictionary/english/paradigm

TABLE 2 Actions on behalf of the research funding and supervising authority to induce implementation/innovation-oriented work in their funded research projects.

Stage	Phase of the work	Potential actions
Pre-project	Formulation of the research consortium[a]	o Include end-users (a minimum representation of 25% recommended). o Include other relevant stakeholders with priority to industrial entities that could undertake post-research technology implementation actions. o Include partners with specific roles or expertise in implementation—exploitation issues such as IPR organizations, business management firms, market analysis and promotion companies, etc.
	Proposal evaluation	o Establish proposal evaluation criteria that include description of the exploitation potential or capacity of the proposed research work and possible actions that could enhance it. o Include in the evaluation team experts with business/market expertise to assess the proposal's business/market potential. o The evaluation reports should challenge projects on their exploitation potential and demand relevant changes. o Proposals should be encouraged to put in their workplan work packages that will be focused on exploitation and market uptake in the results.
	Description of the work to be done	o The policy objectives addressed by the project should be stated clearly together with proposed ways to reach them. o The work plan should include preparation of a road map and a business plan for the exploitation of the results. This could be made compulsory depending on the type of the research. o In the separate work package dedicated to exploitation, a section on the arrangements for securing the Intellectual Property Rights—IPR, should be included. o All partners in the consortium should declare what will be the benefit of the potential results for them.
	Formulation of the research contract	o The research contract should include (among its other provisions): o Expected impact from the deployment of the potential results. o Specific Key Performance Indicators (KPIs) and reference baselines as far as possible. o Specific reference to the obligation for a partner "exploitation agreement" in which the partners should specify their involvement in the exploitation—implementation of the project's results.
During the project	The role of the project officer	o Besides the usual project officer supervising the research project's progress, the funding organization should establish a select virtual team of Project Officers (PO) and reviewers with specific skills to monitor exploitation issues during the project's execution. It should then utilize this team to offer advice and incentives for the post-research implementation of the results should the progress of the research show that such implementation could have promising results. o The PO should be charged with liaison with the team of implementation officers. o Allow the PO to be more involved in the dissemination of information. o Prepare some standard items in the deliverables (perhaps by way of establishing specific templates) that highlight exploitation for the final and publishable project results.
	Project supervision and reviews	o Allow changes in the project work plan to facilitate an easier exploitation. o Facilitate the development of standards as necessary. o Perform mid-term and final review of the project's progress including focus on the exploitation capacity of the project's results. o Push for links to the users (industrial or other). Such links should be compulsory.
	Introduction of flexibility	o The funding organization, through the PO or other experts (e.g., a business reviewer), should actively support the project execution and be flexible in allowing changes to the workplan, as necessary, that would enhance for the exploitation of the results (e.g., exploitation seminars or workshops that may not have been foreseen in the original workplan). o Allow specific support in terms of individual experts or partners to

(Continued on following page)

TABLE 2 (*Continued*) Actions on behalf of the research funding and supervising authority to induce implementation/innovation-oriented work in their funded research projects.

Stage	Phase of the work	Potential actions
		be called halfway if judged essential for the preparation of the exploitation of the results. o Allow and/or incentivize contacts and cooperation with individuals and/or organizations that will facilitate implementation of the results. Examples: include an IPR/exploitation expert in the project meetings or connect with relevant organizations that can supply market/commercial expertise such as (for Europe) the *Enterprise Europe network*.
	Produce an exploitation plan	o A specific exploitation plan (business plan for exploitation) should be mandatory to be presented and discussed during the last mid-term review of the project so as to allow time for potential changes. o The draft business plan for exploitation should be scrutinized and finalized before the end of the project.
	Prepare to face failure	o Research projects may not always produce concrete and implementable results or may not fulfil their expected outcomes. This should be allowed with no major consequences unless of course there are causes of sever negligence, and other unjustified causes for failure.
Post project	Provide support for post-project implementation activities	o For suitable successful and promising project results provide post-project financial support for specific activities regarding implementation of their results. o Feed-back of project results to informational portals or Organizations (For Europe e.g., to the *Enterprise Information Portal*—EIP or the *Enterprise Europe network*—EEN, of for China the *public technology service platforms*). o Organize exploitation brokerage events. o Support (financially and otherwise) the creation of “advocacy coalitions” that are positive towards potential applications of this or similar projects’ results and creation of innovation (see also section 3.3 below).
	Keep monitoring and continue contacts with research coordinator	o Establish ex-post impact assessment of project results (e.g., 1–2 years after the end of the whole research program). o Ex-post evaluation of the program/project management. o Allow funding for a follow-up survey of past projects (1–2 years after project end) for uptake of ideas/results into policy and uptake of ideas/results in the market.
	Formulate and use specific implementation instruments such as…	o Post research implementation funding contracts (through special calls for proposals). o Prizes for good examples of exploitation. o Contest for best projects in exploitation.

[a] In the EU, there are mechanisms established to help for partner search (e.g., the *European Enterprise Network* (small and medium sized companies), or the *European Innovation Partnerships* forum, and others.

According to Bonvilllian and Weiss, paradigms are essential in explaining the resistance of legacy sectors to an innovation that might threaten to disrupt existing business models and harm the stakeholders who benefit from them (Bonvillian and Weiss, 2015). Paradigms can therefore be positive if they satisfy the needs of the users and the larger society or negative if they lure people from those needs. According to the iconic work of Thomas Kuhn on the structure of scientific revolutions the bulk of normal science consists of problem-solving within a given paradigm (Kuhn, 1962). Paradigms allow scientists, engineers, and entrepreneurs to move from intellectual anarchy to a world in which disciplined, progressive scientific and technological activity can flourish (Kuhn, 1962).

It is to some key *paradigms* for transport sector innovation creation, that we turn our attention now aiming at clarifying further the mechanisms that influence transport research implementation and creation of innovation.

4 The impact of transport research implementation in a select number of paradigms

4.1 Connected and smart Automated urban mobility

Automated mobility (the ability of cars and trucks to move freely everywhere without a driver) has become, perhaps, the most eagerly researched theme in the last decade. The research in this area promises to result in the most revolutionary innovation in the field of Transportation since the advent of the internal combustion engine at the beginning of last century (Jones et al., 2023). A large body of transport research has been going on in this field since the early 90’s but most heavily since the beginning of this century. The research work goes on collaboratively with diverse stakeholders and has so far focused on the design of automated vehicle technology, data communication systems for the connected vehicles of the future, relevant services, and infrastructures.

The research results (not only in the automated mobility area but more generally) come to the market through three main channels:

a. By the automakers and other related industrial or commercial firms who take ownership of the research results through financing the corresponding research, or buying the research performing entities, or the patents issued for a specific innovatory research result, or employing the individual researchers who produced the results. In this way, innovatory automated driving systems of up to level 3, of the 5 levels of driving automation introduced by Society of Automotive Engineers—SAE[8], in many new car models that are in the market.
b. By intermediary organizations, privately or publicly owned, who incorporate many interested and relevant organizations in automated driving from various sectors. These organizations act within the wider mobility innovation ecosystems that exist in a given country or area and in effect they energize them as facilitators. They promote automated transport and mobility through testing and demonstrating its technologies or its potential services and investigate new ways of creating value. Typical examples of such intermediate organizations are, the University Technology Transfer Offices (TTOs) that, starting in the late 90's[9] Almost all major universities have now developed within their grounds TTOs with the sole purpose of promoting the implementation and commercialization of their research results. Another example of innovation intermediary is the *Smart Mobility Living Labs* that have been created in many European cities with the support of the EU during the last decade (see for example, the *Smart Mobility Living Lab London* - https://smartmobility.london/or the *Thessaloniki Living Lab* - https://www.smartmlab.imet.gr/). Other examples include organizations like the several *Innovate UK* organizations, each focused in specific innovation area (e.g., Transport), under the *UK's Research and Innovation* organization (a public body sponsored by the UK Department for Science, Innovation and Technology). In China the innovation intermediaries are many and varied. They mainly come in the form of the so-called *Transport Technology Collaborative Innovation Centers* (of which there exist more than 50). A concise review of innovation intermediaries and the literature streams that analyze them can be found in (Caloffi et al., 2023).
c. By governmental financial support for real life demonstrations. This is a practice in both the EU and its member states as well as in the Chinese government i.e., to fund real life applications and demo projects with the purpose to test, validate, and demonstrate a certain innovatory technology or process. In the case of smart and automated mobility a typical example of such practice is the EU funded project SHOW (*SHared automation Operating models for Worldwide adoption* - https://show-project.eu/). This project aims to support the real-life deployment of automated vehicles as part of the shared, connected and electrified mobility concept in major European urban areas. The SHOW project includes real-life urban demonstrations taking place in 20 cities across Europe with testing of fleets of automated vehicles in public transport, demand-responsive transport, Mobility as a Service (MaaS) and Logistics as a Service (LaaS) applications. The project gathers a strong partnership of 69 partners from 13 EU-countries and fosters international cooperation by collaborating with organizations from the US, South Korea, Australia, China, and other countries.

Similar examples exist, at national level, in Europe, the US, and China. For example, the UK government has announced in May 2022 the *Commercializing Connected and Automated Mobility* competition[10] through which it is providing grants to help roll out commercial applications for uses of automated vehicles across the UK as of 2025. In the US, the *Federal Laboratory Consortium for Technology Transfer (FLC)*[11] is a nationwide network of over 300 Federal laboratories, agencies, and research centers that fosters commercialization best practice strategies and opportunities for accelerating federal technologies from out of the laboratories and into the marketplace. Also, the *Small Business Innovation Research* (SBIR) and *Small Business Technology Transfer* (STTR) Programs, help innovative small businesses meet federal R&D needs and commercialize those innovations through outreach, training resources, and helping entrepreneurs connect to local resources[12].

At governmental level, strategies to introduce and integrate the automated vehicles with the rest of the traffic on the existing road networks and the development of the necessary infrastructures (communication infrastructures, control, and supervising centers, and so on), are also a prerequisite. China's *National Development and Reform Commission*, the Ministry of Industry, and Information Technology (MIIT), and 11 other ministries and commissions have jointly issued a strategy, in 2020, for the innovative development of autonomous vehicles. This strategy involved the following goals for 2025:

✓ Intelligence. The large-scale production of L3 vehicles (autonomy level 3) and the market launch of L4 vehicles in selected scenarios.
✓ Connectivity. Long-term evolution of vehicle-to-everything (LTE-V2X) connectivity with sufficient area coverage will be realized, with fifth generation V2X (5G-V2X) network coverage featuring high-precision space-time benchmarks (for some cities and on some highways).

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[8] See: J3016_202104: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles - SAE International

[9] See an earlier day inventory of such activities in (Perkman et al., 2013).

[10] See: https://www.nibusinessinfo.co.uk/content/commercialising-connected-and-automated-mobility

[11] https://federallabs.org/

[12] https://www.sbir.gov/

- ✓ Standardization. A set of Chinese standards for automated driving will be put in place (these are being developed based on the results of the many real-life demonstrators that have been set up in China).

The December 2021 the McKinsey Center for Future Mobility survey[13] found that Chinese consumers are more likely than Western consumers to embrace autonomous driving, more enthusiastic about autonomous functionalities, and more willing to pay for them in terms of purchasing L4 vehicles. Another research investigating the impact of connected and automated mobility on the number of vehicles on the road and the vehicle kilometers travelled (VKT), found that automated mobility is likely to increase the VKT and thus increase instead of reduce congestion unless it is combined with shared mobility (see 4.3 below) and a shift from ownership to usage through shared mobility schemes (buying rides, not cars). According to the Boston Case Study, of MIT's Automated Mobility Project, fully automated vehicles incorporated into ride- and car-sharing solutions could reduce the number of vehicles on the road in Boston by as much as 80%. Other research streams have investigated the optimization of car sharing schemes and showed that once customers are willing to accept a booking process based on optimization-matching mechanisms, there will be considerable improvement of services (Weidinger et al., 2023).

A particular case of research results paving the way to automated mobility applications are the various simulation models that are developed to test and validate connected and automated transport traffic conditions. These research results are more likely to be implemented in a relatively short time because their implementation does not require extensive investments and the lengthy procedures but also because they reduce the overhead and development time necessary for the development of other connected and automated transport innovations. Typical examples of such simulation packages are the simulation packages for automated transport developed within specific research projects like the SHOW project mentioned earlier or the *Next-Generation Simulation Model* (NGSIM) platform in the US or the *Autonomous Driving Simulation System* (AUTOSIM) developed by Beijing Jiaotong University in cooperation with other entities in China (the GAC Group, DIDI company, CATARC, CAICT, MXNAVI, and Jilin University). The AUTOSIM model is a multi-sensor data fusion simulator including various dynamic simulation models and a large-scale traffic flow simulation. It allows testing the performance of autonomous driving under various conditions, and its evaluation under different traffic, safety and navigation conditions (Qin et al., 2023).

4.2 Intelligent railway systems

In the EU the rail network, of all its member countries excluding the UK, had a total length of more than 220 000 kms in 2020 of which 12 000 kms were high-speed rail of up to 300 kms/h. The length of the Chinese rail network is over 150 000 kms of lines of which some 44 000 kms are high-speed rail of more than 300 kms/h. The railways in both regions carry billions of passengers every year making this mode of transport a key part of the national transportation systems. Innovation in the railways plays, therefore, a key role in securing smooth operation and development in the sector and governments as well as the railway companies spend considerable amounts of funding for research and innovation in the rail sector. Rail research in the EU is primarily funded through a special agency of the European Commission called *Europe's Rail* (https://rail-research.europa.eu/). This agency is the successor of another well-known rail research program called *Shift2Rail*. Of interest is the new approach that is followed by *Europe's Rail* in which the implementation of the research results is a process that is built-in with the research planning and execution stages. This is shown by the way they have designed their current major research project, Flagship Project 4 (FP4) Rail4EARTH or *FP4-RAIL4EARTH*. This is a research and implementation project worth EUR 95.1 million with 71 partners that is led (coordinated) by a well-known industrial company in the field of rail equipment, the French ALSTOM. The activities in the FP4-RAIL4EARTH project cover rolling stock, infrastructure, stations and all of their related sub-systems (traction, bogies, brakes, energy storage systems, heating, ventilation and air conditioning). The interesting part in this holistic approach is that with the same contract a high number of 38 demos have also been envisaged to be executed at the end of the project. So, with the same contract the FP4-Rail4EARTH project will demonstrate its expected results in real life demos planned to take place through six implementation sub-projects in the following areas: Alternative energy solutions for the rolling stock, Energy in rail infrastructure and stations, Sustainability and resilience of the rail system, Electro-mechanical components and sub-systems for the rolling stock, and Healthier and safer rail systems. Overall policies in the rail sector and supplementary support for the implementation of research results is done by the *European Union Agency for Railways* (ERA—https://www.era.europa.eu/).

In China, a key role in implementing research and creating innovation in the railways is played by the *centers for collaborative innovation* in the railways. These are centers of collaborative research involving universities, research centers and private or public enterprises in the relevant fields, which develop (mostly through publicly funded research) research results and then support their implementation to specific problem areas. The centers for collaborative innovation are created at national, or regional, or even local level (by municipalities). A good example is the (national lever) collaborative innovation *Center for Coordinated Innovation of Rail Transport Safety* which was established in August 2012 by the Beijing Jiaotong University and includes two more universities (Southwest Jiaotong University, and Central South University), as well as three major private companies active in the field of railways, the *China Railway Science Research Institute*, the *China National Vehicle Company*, and the *China Railway Construction Company* (see China Railway (china-railway.com.cn)). This center has developed research with relevant results in producing innovative systems for, the train

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[13] McKinsey Center for Future Mobility (MCFM) 2021 ACES (Autonomous Driving, Connectivity, Electrification, and Shared Mobility) Consumer Survey.

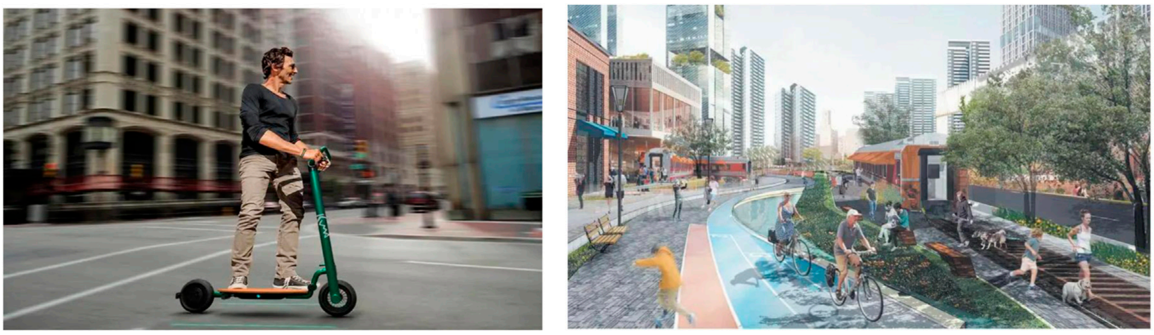

FIGURE 1
Three main types of micro mobility: walking, bicycling, and e-scooter.

(mobile device detection and monitoring/in-vehicle train control/in-vehicle information and decision-making/vehicle-vehicle communication/in-vehicle communications, etc.); the train station (station signals interlocking control/ticketing and reservation/signal detection/automatic ticket checking/freight/package operation); the train track (disaster monitoring/infrastructure monitoring/accident monitoring/track circuit transceivers/mobile device monitoring, etc.), train control center (navigation/resource management/integrated transportation/maintenance management/emergency and safety management, etc.). Furthermore, the *Intelligent Patrol Inspection System for Railways* (PIR) was also developed by the center's partners for China Railways, and this has been implemented providing advanced algorithms and software supporting the real-time and high-precision inspection for high-speed railway infrastructures including rails and power grids. Implementation of all these results has so far been secured by the research partners of the *center* i.e., the three major railway companies mentioned earlier. In addition, several *innovation platforms*, were created aiming to promote these research results and cultivate innovation with the involvement of more relevant stakeholders. Having in the same group (the center) a mixture of research and industrial or user partners has made implementation of the research results easier.

4.3 Shared and micro mobility options

Micro mobility has become a modern way of traveling in congested urban streets, used mainly by young or relatively young persons. It includes several transport modes including pedestrian (walking or jogging), wheelchair, bicycle, tricycle, electric bicycle, electric scooter, roller skating, and similar (Figure 1). It is a slow traffic system with speeds below 15 km/h (the Chinese refer to it as "slow traffic system"). There is a large body of literature published on this transport mode (see for example Liao and Correia, 2021) and the results so far point to a mixed blessing situation in which the benefits of this type of mobility e.g., consuming less travel and parking space or protecting the environment, are outweighed by the reduced safety that this mode has demonstrated so far and by the lack of protection in cases of adverse weather.

Shared mobility is the general term used to denote the use of a vehicle that is not owned by the user. It is distinguished in *car-sharing* which is the usage of a vehicle fleet by members for trip making on a per trip basis and *ride-sharing* in which a passenger travels in a private vehicle driven by its owner, free or for a fee, as arranged by means of a website or app. Shared mobility provides users with short-term access to a car (or other modes of transport like e.g., an e-scooter, or bicycle) as it is needed. Earlier, as well as on-going, research work on shared mobility has been instrumental in demonstrating the value of shared mobility for reducing urban vehicle trips and developing shared mobility apps that facilitate the operation of shared mobility as a service schemes (Heineke et al., 2021; Jia-Wei and Creutzig, 2021; Liu et al., 2022;). Examples include, in Europe, the *SocialCar* project that ended in 2018 (Project reference H2020- 636427—see CORDIS data base https://cordis.europa.eu/project/id/636427). This research developed a car sharing app (the RIDEMYROUTE app) which claims to have demonstrated that such an app can reduce commuting vehicle trips from −10% (in Zagreb) to −45% (in Edinburgh) and increase public transport users from +7% (in Zagreb) to +35% (in Brussels). In China, similar types of research projects have produced relevant results. For example, the project iSTAP (*Intelligent slow traffic system assessment and planning*), assigned by the Beijing Municipal Commission of Transport, has produced a system of low-cost models for micro-mobility and shared-mobility assessment and planning, by using novel machine learning algorithms based on multi-modal traffic data (UPSC, 2021). The same research project developed 14 indices to evaluate the performance of these systems and has computed their values automatically by multi-source multi-modal data collection and analysis.

Shared mobility research has provided policymakers with ample evidence of the effects and impacts of shared mobility pointing to the most efficient and effective way of implementing shared mobility schemes. It is now evident, from past and on-going research, that car-sharing alone increases the vehicle kilometers travelled whereas car-sharing and ridesharing together have the potential to decrease them (Liu et al., 2022). Furthermore, when considering shared automatic vehicles it is shown that under the shared mobility scenario with 100% ride-sharing and car-sharing participation levels, one shared autonomous vehicle can potentially replace

3.80 private conventional vehicles in the road network (Liu et al., 2022).

Shared mobility research is a good example of transport research implementation having dozens of research results being implemented by shared mobility companies and policymakers alike. Only in the US in 2020, more than 40 million e-hailing trips (ridesharing) were booked on the two biggest e-hailing platforms Uber, and Lyft, every day and the number of these trips almost tripled in the 4 year 2017–2020 while the number of micromobility trips more than doubled between 2020 and 2021 (Heineke et al., 2021). According to McKinsey's 2020 ACES (**A**utonomous driving, **C**onnected cars, **E**lectrified vehicles, and **S**hared) consumer survey in the US, more than 60% of people would share their ride with a stranger if doing so would add less than 15% to their travel time while reducing their cost. Another survey and simulation analysis, in Europe this time, found that higher educated and more time-sensitive respondents are more inclined than others to favor (automated) car-sharing options and that the preferences towards shared (automated) vehicles and free-floating car-sharing are highest for those currently combining car and public transport for their commute (Winter et al., 2020).

4.4 Electric mobility

Electric mobility is another revolutionary innovation that is currently unfolding. It started a few decades ago mainly as a response to the adverse environmental problems caused by urban traffic pollution and the use of fossil fuels in internal combustion engines (ICE). Then the realization of the impeding climate change and the need for mitigation measures to stop or delay it, gave electrification another "push". We are now at a phase where:

- o In market terms, electric mobility is still a small percentage compared to conventional ICE mobility with very few exceptions (e.g., Norway). The main reason seems to be the purchase price of electric vehicles (that is generally higher than that of conventional vehicles) and the insecurity felt by drivers of electric vehicles about finding a charging station available. As regards the cost, however, very few users realize that the overall operational cost of the electric vehicles is already cheaper than that of an equivalent vehicle with ICE (Grey and Hall, 2020).
- o Public opinion and consumers' behavior concerning electric vehicles is currently under formulation. It is expected to mature and stabilize within the next 5–6 years.
- o The technological capabilities for the batteries of electric vehicles increase rapidly as their cost falls and this is a positive trend (Liu et al., 2022; Islam, 2023).
- o In As of 2023, all auto manufacturing firms have offered to their customers several electric models with many extras offering attractive operational and technical characteristics to the user. As a result, so of this but also of various incentives and subsidies offered by governments, the number of electric vehicles sold as a percentage of the total increases rapidly.
- o The electricity generation systems are becoming more sustainable, and this results in cleaner energy production as well as in its more efficient distribution and management. For electric mobility to be truly effective in environmental protection the electricity generation system must be clean and based on renewables.

To come to this point, it took more than 3 decades of research efforts and quite daring political decisions that "pushed" the auto manufacturing community to substantial investments for producing new types of batteries and electric motors. This research effort has been substantiated and reviewed by several authors (Kim et al., 2019; Grey and Hall, 2020; Hosaka et al., 2020). Lithium-ion batteries (Li-ion), which depend on lithium and cobalt ore resources, are currently the most widespread and reliable source of energy for electric vehicles. Research, however, is still going strong on alternative configurations due to the projected scarcity of these two resources in the future and new forms of batteries are being developed. The potassium-ion batteries (K-ion) are emerging as a promising complementary technology to L-ion due to the relative abundance of potassium (Dhir et al., 2020).

Implementation of battery research has been rather quick to materialize because of the strong political interest in electrification and the equally strong response of the industry in this area. The story of electrification in the BMW group is quite indicative of the process of research implementation and innovation creation in this area. The group started its research and development on electric batteries/vehicles in 1972 for demonstration at the Munich Olympic Games[14]. This research was performed primarily within the BMW group with the help of a number of select subcontractors. The results of the first 20-year of research work and development effort were presented in the 1991 International Motor Show in Frankfurt, Germany, as the first purpose-built electric city-car model of BMW. After 1990 with the advent and development of the EU funded research programs, BMW participated in collaborative (public) research projects in consortia financed by the EU. Its main research effort was, however, still financed internally i.e., by the company's research and development budget. Between 1992 and 1996, eight electric BMW 325 models were put experimentally in service on the island of Rügen, off Germany's Baltic coast, to test various motor, transmission, and battery configurations under everyday conditions. For the first time, the company produced a commercially available fleet of (more than 600) electric vehicles in 2008. So, it took 40 years for a powerful auto manufacturer in Europe to research, develop and implement electric technology innovation primarily produced by internal research (i.e., financed by the group). A similar path to electrification was followed by the other two iconic European manufacturers, the Mercedes-Benz and the Volkswagen groups (Cremer and Schwartz, 2017; Lambert, 2018).

In the case of the People's Republic of China, the road to electrification and the implementation of research results to create electric vehicles, took an even faster and more straightforward road. This was largely due to the strong

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[14] The information in this paragraph comes from the BMW group's historical records as it is presented in, https://www.bmwgroup.com/en/news/general/2022/50yearselectromobility.html

governmental intervention and support for electrification which left a distinct impact on the speed of implementation. The Chinese strategic policy known as "Made in China 2025", that was put forward in the early 2010s, foresaw transforming China to a high-tech, world-dominant country in 10 advanced industries one of which was transport and electric vehicles. In later refinements of this policy, China has set its goal to become a global leader in "new energy vehicles" by 2030. In implementing these policies, the Chinese government started in 2016 a strong financial subsidization plan which provided billions of dollars' worth of subsidies and research grants to support research and implementation (manufacturing) activities for electric vehicles and electromobility. This funding was, for the 5-year period 2016–2021, of the order of $60 billion. In parallel, an equally heavy public spending was approved for installing fast battery charging stations across the country and as early as 2017 there were already 171,000 such electric charging stations all over China (Giannopoulos and Munro, 2019).

China today is the world's largest maker of electric vehicles and by 2030 it is expected to account for approximately 60% of the world's electric vehicle sales. As regards clean electric energy generation, here too China leads the world with more than 3-times more spending in 2022 on solar and wind energy, than the United States or the European Union (FitchRatings, 2023; Schonhardt, 2023). At the same time, however, China is still the world's largest user of coal and other fossil fuels for electricity generation and in the past decade it used more than half of all the coal consumed in the world, for power generation. According to press reports, in the first quarter of 2023, provincial governments in China have approved at least 20 GW of new coal projects and in this way in China more coal power was approved to be used in the first 3 months of 2023 than in the whole of 2021 (Li, 2023; Hawkins and Cheung, 2023).

The process of transport research implementation and innovation creation in the electromobility area is connected to two strong *advocacy coalitions*. On the one hand, the pro-innovation coalition that is in favor of the electric—and more generally, "clean"—mobility and the expansion and ubiquitous operation of renewable energy sources, and on the other hand the legacy coalition which supports the delay of decarbonization and electrification and the continuing use of internal combustion vehicles and conventional fuels for as long as they are available supplies. From experience so far, which advocacy coalition will win the battle over electrification and decarbonization in the future will depend on "internal" as well as "external" influencing factors. The first category primarily includes the maturity and market expansion of the innovative clean technologies developed by research and development funding and the adoption of reliable and long-term policies for the promotion of such technologies which means existence of steady and strong political will. The second, includes primarily the non-easily foreseen external influencing factors like wars, physical catastrophes, or political change. For now, in both Europe and the United States as well as in China, the political climate is in favor of the electric and clean mobility "revolution". However, this can easily change in the future e.g., because of political change in the United States The European Union is so far probably the most advanced in the world in taking concrete measures and setting policies for clean (and electric) mobility in a holistic way (including clean energy generation).

5 Discussion and conclusion

Transport research implementation is the usual if not mandatory condition for innovation creation in the transport sector. It consists of all the necessary actions that aim to move the initial research results from their theoretical formulations to real world testing and application for eventual maturity towards market-oriented products. The stage of research implementation also includes extensive field testing, adaptation, and prototype production as necessary. As it was shown in the case of the research for automated mobility as well as for electromobility, research implementation usually takes place immediately after (though not necessarily) the research stage and is materialized through one or more of the following:

a. Implementation actions by the research performing entity. This is usually the case of large privately or publicly owned companies who have a vested interest in the research and expect economic benefits from its implementation. A good example of this type of entities are the large universities who install special implementation units to help transfer their research results into commercial products and services for the (economic) benefit of the University and its researchers. An alternative way of action here is to secure the IPRs and then sell those rights after an initial set of implementation actions such as a proof of concept or a real-life demo. Another type of research performing entities moving directly to implementation by their own funding are large industrial companies such as the auto manufacturers or the original equipment manufacturers (OEMs) who invest on the research to obtain solutions to specific problems and issues. Implementation then, is a predetermined decision provided of course that the research results will be successful and promising. Confidentiality and obtaining commercial value are the primary concerns and characteristics of this type of research implementation.
b. Intermediary organizations privately or publicly owned, who act as facilitators of innovation. These are usually umbrella organizations that incorporate several other interested and relevant organizations in the broad area of the research field they support. They undertake to promote implementation and help in finding finance for it, focusing mainly on small or medium sized research performing entities. The various University Technology Transfer Offices (TTOs), or Technology Licensing Offices (TLOs), or the various forms of technology alliances, enterprise incubators, virtual web-based platforms for interconnection and partner finding, etc., are forms of such intermediary organizations. These are found in both Europe and China (see also Section 2.2) with the difference seen on the type and extend of the background legislation for their operation and funding.
c. Governmental (financial and other) support for real life demonstrations and implementation studies. Several governments at central, regional or local level are now developing and offer specific research implementation programs in order to finance research implementation. They issue calls, just like a research call, for financing implementation activities such as field testing and proving

> and further development of initial research findings. In the case of publicly funded research there is a growing need for funding such an implementation/integration stage after a research project has been completed. Implementation funding should be given after evaluation of the implementation potential of the research results and should aim at funding real world testing and technology maturity/demonstration actions. The examples of the European Union government's call for implementation actions as well the various similar calls by state authorities in the United States[15] are quite indicative of this trend. A key issue here is to streamline and make the possibility of providing implementation funding should be known early in the research stage and even acknowledged in the initial research contract. Our (innovative) detailed proposals in his respect are given in Table 2 of Section 3.2.

The existence of *governmental support and political will* to take supportive measures for research implementation and put in place the facilitating legislative frameworks, is a fundamental facilitating factor. It consists of accepting open sources of financing and providing the necessary legislative frame for accepting real world testing of new vehicles and systems, updating safety regulations to cater for new forms of mobility (as for example in the case of real world running of automated vehicles), and prescribing new forms of cooperation and entrepreneurship between the innovation ecosystem stakeholders. To fulfill its role in this sense, the public sector needs to cooperate fully with the private sector and other innovation stakeholders to design together the necessary measures and policies in each case. Supporting start up entrepreneurship and giving incentives for privately funded innovation initiatives for post-research implementation is another role that the public sector is called to play. Although most governments pay lip service to the importance and need of scientific research implementation and creation of innovation as a key to economic growth and development, they have so far fallen short of taking bold supportive measures and adopting long-term policies in most countries of equal importance is the existence and active participation in post-research implementation activities of a healthy and vibrant private sector. In fact, it is the private sector who should take the lead in initiating such activities and—if necessary—formulate, plan and finance new innovation ecosystems. This has been the case in the United States and the European Union for many years now, but it is also becoming particularly visible in later day China where a strong governmental presence, at central or regional level, sets the policies and takes supportive measures but then a vibrant and very active private sector takes over to produce innovation. The Chinese experience has still a lot to offer us in that it would be of interest to see what happens when such an extensive public financing is ended. In the case of transport electrification in China the impressive results that have been achieved so far have relied to a strong public financing, but it will be of interest to see what will happen when such financing stops.

Creating lean and flexible "pools of cooperation" for research implementation is another interesting facilitator element that came apparent from our analysis in the previous sections. This differs from the concept of an innovation ecosystem, which is much wider, but it can be thought of as a helping step towards it. A "pool of cooperation" is an approach seen mostly in China and can range from participation and interaction via a simple internet platform, to the creation of an "innovation area" by virtually or physically putting private or public industrial or commercial or consulting and research entities in contact and "proximity". In this way, economies of scale can be created using common infrastructures to achieve important multiplying effects. The *Silicon Valley area* in the US is one of the earliest and most well-known example of a physical and virtual pool of cooperation for research implementation but so are the many "innovation zones", "science cities", technopolises, and so on, that exist in many European countries. The governments may assist the creation of such "pools of cooperation" by providing initial support (from the provision of low-cost land to low-cost financing) and safeguarding their sustainability by allowing for low-rate loans, tax incentives, etc. Such innovation infrastructures are key innovation ecosystem elements, providing proximity and interaction opportunities between stakeholders. The existence of a large University or research center inside or close to these areas is a big factor of success. Graduates of these universities are likely to become the entrepreneurs that develop or join the startups that normally locate there.

To conclude, and by referring to our initial "research questions" i.e., how is the notion of "innovation ecosystem" materialized in the European Union and China, what is the current picture as regards innovation creation and implementation of transport research in each of these two regions and, finally, what can be done to facilitate better use of the results of transport research and increase its impact on innovation, we hope that the previous discussion has answered the last of these three questions. As regards the first and the second, our investigation and analysis of the four cases of innovation production shows that in both China and the European Union all the necessary "ingredients" of innovation ecosystems are in place and operating but the strong central government support and financing that is provided in the case of China makes for a distinct advantage. This is seen in faster innovation cycles and market uptakes as it is well demonstrated in the example of electric mobility. When looking on the post-research contract phase of research results implementation, both areas are making progress in trying to associate research with its implementation phase right from the beginning, but some key ingredients of success need further support and refinement. In both areas, the institutional (bureaucratic and political) structures still create regulatory hurdles that impede the process of innovation while the rights of the innovator-researcher and technical worker need to be secured further. Post-research implementation financing remains generally scarce and takes long times to approve and deliver. This restricts a balanced, robust, holistic and above all sustainable innovation financing system to exist and discourages innovative researchers—entrepreneurs from taking risks by using the banking loan system. Furthermore, the social and political acceptance of new technological or process potential innovations, especially if this is of a "revolutionary" level, is something that needs to be better integrated with the testing and maturing of new technologies as it is amply demonstrated by the "automated transport" innovation experience.

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[15] See for example the State of Minnesota's research implementation program in: https://www.dot.state.mn.us/research/implementation.html

A most positive element favoring post-research implementation activities support and financing is the existence, in both Europe and China, of a strong basis of educational institutions and skilled human resources of high professional standards that are accustomed to new ideas and favoring innovation. This is very important as these human resources can easily form the necessary strong "cores of attraction" in the innovation ecosystem i.e., initial groups of competing and collaborating innovators that will push the system above a minimum critical mass that is necessary to achieve sustainability. It is advised that in both areas legislation should be examined to create national structures that favor research implementation by, for example, incentivizing the domestic production capabilities in a way that maintains a technological workforce that can produce and commercialize research results. A well-funded, by private or public sources, but government-supervised research and development program that includes post-research implementation financing committed to real life testing of solutions to fundamental scientific and technological problems is what needs to be put in place more efficiently, in both Europe and China.

Having a regular, transparent, and steady cooperation between the public and the private sectors is a fundamental facilitating factor in a post-research implementation structure. Over the long run, the private sector will always be the basic force of innovation production in any successful innovation ecosystem but the public sector who sets the rules and frames of operation and brings in the wider societal perspective is equally important and crucial.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

GG: Conceptualization, Writing–original draft. YL: Investigation, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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