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Copyright Statement

Modus

MODELLING AND ASSESSING THE ROLE OF AIR TRANSPORT IN AN INTEGRATED, INTERMODAL TRANSPORT SYSTEM

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Abstract

In the context of increasing environmental awareness, regulatory measures, capacity shortages across different modes, and the need for a more seamless passenger journey, the optimisation and alignment of multimodal transport in Europe is therefore of the utmost importance for the overall performance of the (future) transport system. In line with this, the high-level objective of Modus is to analyse how its performance can be optimised by considering the entire door-to-door journey holistically and air transport within an integrated, multimodal approach.

Within this context, Modus Deliverable 3.1 has the objective to identify and assess (future) drivers that influence passenger demand and supply of mobility, and how these affect passenger modal choice. A comprehensive literature review is provided and identifies a set of high-level and detailed drivers of supply and demand. This analysis is complemented by an expert survey, to gain initial high-level insights regarding the potential importance of various factors, and by a multimodality workshop, to identify additional factors and acquire a first insight into potential enablers and barriers of future mobility solutions.

Combining all the identified drivers reveals that most drivers are of a social, economic or technological nature. A large number of social drivers are demand drivers concerned with the passenger aspects of mobility. On the other hand, a large number of economic drivers belong to the supply drivers concerned with various cost-related factors or with transport operations, the market structure and available infrastructure.

The way to integrate these drivers into a modal choice analysis is strongly related to the type and quality of data available, as well as to the project's model objectives and expected results. This report therefore provides an overview and discussion on various commonly-used econometric transport demand models and explains their usefulness and potential limitations or constraints.

These insights with regard to trends and developments yield a valuable contribution for the setup of the Modus modal choice analysis, use cases, and scenarios, as well as recommendations for improvement potential at a later stage in the project.

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List of Abbreviations

AI	Artificial Intelligence
ANSP	Air Navigation Service Provider
ASK	Available Seat km
ATM	Air Transport Management
CV	Coefficient of Variation
DL	Deep Learning
D2D	Door-to-Door
EASA	European Union Aviation Safety
EC	European Community
EIB	European Investment Bank
EU	European Union
FSNCs	Full Service Network Carriers
GDP	Gross Domestic Product
GTD	Global Terrorism Database
HDI	Human Development Index
HPI	Happy Planet Index
HSR	High Speed Rail
IATA	International Air Transport Association
ICT	Information and Communication Technology
IoT	Internet of Things
IT	Information Technology
ITS	Intelligent Transport System
LCCs	Low Cost Carriers
LCR	Low Cost Rail
MaaS	Mobility as a Service
ML	Machine Learning
NEBs	National Enforcement Bodies
NGO	Non-Governmental Organization
NRS	Natural Resources Scarcity
OADR	Old-Age Dependency Ratio

OAG	Official Airline Guide
PPS	Purchasing Power Standards
RPK	Revenue Passenger Km
SAF	Sustainable Aviation Fuels
SD	Standard Deviation
SDG	Sustainable Development Goal
STEEP-M	Social, Technological, Economic, Environmental, Political and Mobility
TC	Transport Cost
TT	Transport Time
UAM	Drone & Urban and Air Mobility
UIC	International Union of Railways
UN	United Nations
VFR	Visiting Friends and Relatives
4HD2D	4-Hours-Door-To-Door

1 Introduction

In the context of increasing environmental awareness, regulatory measures, capacity shortages across different modes, or the need for a more seamless and hassle-free passenger journey, the future evolution of European travellers' demand for mobility is still unknown, as well as its potential impacts on the European transport system. The optimization and alignment of multimodal transport is therefore of utmost importance for the overall performance of the (future) European transport system, especially in regard to providing a seamless and hassle-free journey for passengers as well as mitigating (air) capacity constraints. In line with this, the high-level objective of Modus is to analyse how the performance of the overall European transport system can be optimized by considering the entire door-to-door journey holistically and considering air transport within an integrated, multimodal approach. This is pursued by:

- Identifying and assessing (future) drivers for passenger demand and supply of mobility, and how these affect passenger mode choice,
- Applying and further advancing existing models to determine the demand allocation across different transport modes, especially air and rail, and the effects on the overall capacity of these modes, and
- Developing and assessing performance and connectivity indicators which facilitate the identification of gaps and barriers in meeting high-level European (air) transport goals, and solutions to gaps can be addressed.

Modus wants to understand in a better way how air transport management (ATM) and air transport can better contribute to improve passengers' multimodal journeys and how this translates into an enhanced performance of the overall transport system. A multimodal journey from door to door comprises different steps, as depicted in Figure 1. The focus of Modus within this door-to-door travel chain is on multimodal transport that includes as a main segment either rail or air transport in Europe. Other transport modes such as public transport are considered as access and egress modes (feeder traffic) to either the airport or the rail station.

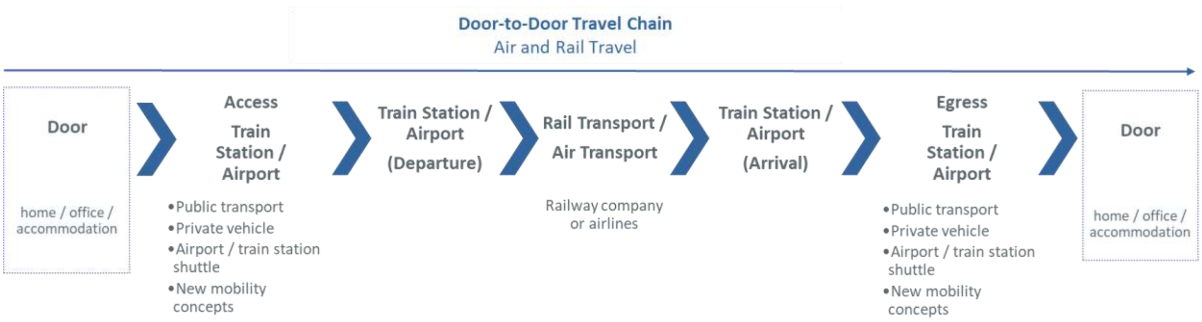


Figure 1: Modus multimodal door-to-door scope

Source: adapted from Schmalz, Ringbeck & Spinler, [1]

Within this context, Modus deliverable D3.1 has the objective to identify and assess (future) drivers that influence passenger demand and supply of mobility, and how these affect passenger mode choice.

The deliverable outlines additional demand drivers than the ones traditionally used in transport demand modelling such as activities that can be performed during travel time, traveller's own perceptions of different dimensions of travel (multimodal) supply (convenience, comfort, predictability, flexibility, reliability, in vehicle-crowding, ecological awareness/"flight shaming", etc.). In parallel, levels and features of air transport and rail supply will be influenced by travellers' expectations and behaviours, but will also be constrained by the regulatory and operational context.

In order to gather, and include in further Modus analyses, a comprehensive overview of these drivers of future demand for and supply of mobility, the following approach has been pursued, combining a literature review, an expert survey, a multimodality workshop, and the initial discussion of passengers' modal choice models.

Figure 2: Identification and assessment of future drivers of demand and supply in Modus

Source: own depiction

First, a comprehensive and detailed literature review outlines multiple factors that influence the future supply of and demand for mobility solutions and services within Europe (Section 2). For each identified driver, a definition is provided as well as an indicator how a driver can be measured, and, when available, the data sources per transport mode to compute the indicator. Based on the results of the literature review and addressing the goals of the Modus project, a complementary expert survey was conducted (Section 3). The survey aims to capture the expertise and assessment of experts from various transport domains in regard to the evolution of the future European transport system. In addition to that, the Modus consortium organized an online workshop with participants from various (transport) domains during which multiple aspects were addressed and discussed which are relevant and essential for a future multimodal European transport system (Section 4). The Modus Industry Board has been consulted both during the expert survey as well as during the multimodality workshop.

Section 5 then presents a literature review on different econometric models that are commonly used to model and assess the modal choice demand of travellers. This section presents the analysis of the objectives, assets and constraints of each model type, and will be useful to help deciding which econometric model will be the most appropriate given the different sets of data that should be available in the Modus project.

The Covid-19 pandemic has also impacted the transport sector in severe ways, and the long-term changes are still uncertain, such as the potential changing working environment with virtual meetings replacing business travel in the short-term and this trend establishing in the longer term, for example. Since Modus focuses on a time horizon of 2040+, long-term developments play an important role in the various analyses, those potentially resulting from the Covid-19 pandemic are hence discussed and reflected in the scenario development in upcoming deliverables. Within this deliverable, short-term developments in this regard are highlighted in Sections 3 and 6.

Section 6 summarises and discusses the findings and provides an overview of the next steps within Modus.

2 Multimodal Supply and Demand

2.1 Introduction

This section presents results from a comprehensive literature review to identify the factors influencing the current and future levels, and features, of transport supply and demand. Given the multimodal scope of the Modus project, air transport and rail transport are both incorporated. There are two approaches for examining these 'drivers' in the literature: **1) high-level drivers** (e.g. GDP development, urbanization, or population growth) and **2) modal choice drivers** (e.g. psychological factors and others arising from a passenger-centric perspective or cost drivers on the supply side). These results fulfil different purposes in the Modus project. The high-level drivers review is used as input for the expert survey (questionnaire). The modal choice drivers are used as input for the modelling exercise. We list all types below in the overview. Indicators for measuring respective drivers, and the correspondingly required data, are also presented. Such indicators could be simple (e.g. minutes), or compound (e.g. ratios, such as euros/hour). Various sources were used in this review, such as project reports, scenario studies, and scientific papers. As we used different sources, multiple researchers and several review rounds within the consortium to conduct this literature review, we made sure to avoid biased results. The drivers presented in this chapter are intended to provide a comprehensive overview of those factors which have a potential influence on the future European transport system. The following section incorporates three foci:

- **Section 2.2: Demand and supply drivers - high-level overview** → input for WP3 expert questionnaire and for the preparation of workshop "The Future of Multimodal Transport: Horizon 2040"
- **Section 2.3: Demand drivers - detailed overview** → input for WP3 modal choice analysis & WP4 passenger mobility modelling
- **Section 2.4: Supply drivers - detailed overview** → input for WP4 passenger mobility modelling

All drivers are further categorised along the STEEP-M framework. STEEP-M is an acronym for Social, Technological, Economic, Environmental, Political and Mobility. The framework has been selected since we can capture and structure a high amount of factors affecting demand and supply within the European transport system. It shed light into which category is represented well and which is less represented across all reviews.

2.2 Supply and demand drivers – high level overview

The first analysis depicts a list of the high-level demand and supply drivers affecting the overall system. Next to providing background literature (e.g. we used the DATATSET2050 [2] project as a basis for this review), these were tested further in the Modus expert survey and discussed in the first workshop in January 2021 ("The Future of Multimodal Transport: Horizon 2040"). Not all of these drivers are used for the modelling exercise but they are all useful for a general discussion of the future directions within the industry and for deriving detailed drivers for the modelling level (for modal choice drivers and supply, mode-agnostic and mode-specific drivers), and will also contribute to further work within Modus such as the development of different scenarios (see deliverable D3.2).

2.2.1 Social drivers

The population size is a significant driver for transport demand, for instance explored for air travel by Abed et al. [3], and the rail sector by Steer Davies Gleave [4] and Wardman [5]. More people ultimately demand more mobility and vice versa. The *Population change in size* refers to a population growth (or decline) due to higher birth rates and higher life expectancy. The change rate is measured by the overall population change in percentage per city/area/country and/or the fertility rate per city/area/country (Eurostat, 2021; United Nations, 2019). Figure 3 depicts three possible scenarios for the overall population change rate in Europe until 2100. Only scenario one (blue line) with a high fertility rate depicts a long-term positive change rate until 2100. In line with that, *Immigration*, for instance into Europe measured in yearly numbers of immigrants [6], and *Urbanisation*, meaning more people living in urban and suburban sprawl ([7]), can also be positive drivers for more transport supply and demand (in terms of infrastructure). Figure 4, for instance, depicts a correlation between population density (measured in population / km^2) and track utilisation (measured in train km / track km) among European countries [4]. We also see in Figure 4 that some countries, such as Sweden or Finland, have a higher track utilisation but low population density. An explanatory factor might be the countries' geographies and connection of rural regions. To sum up, it seems essential to know the amount of people (*Population change in size & immigration*) and where they live (*Urbanisation*).

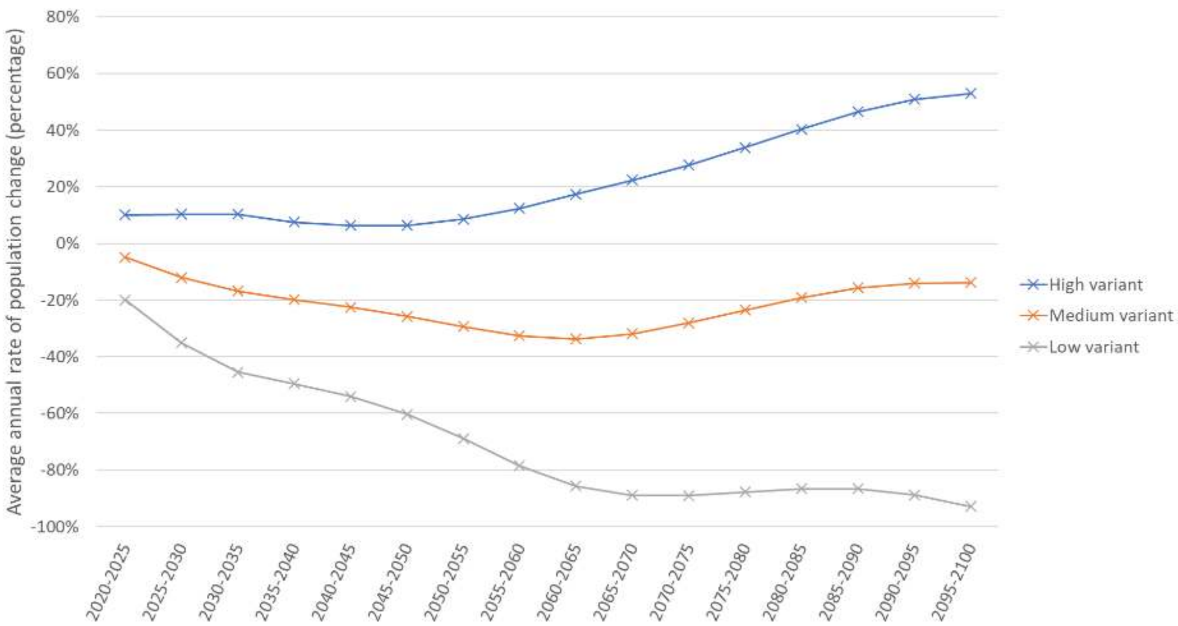


Figure 3: Average annual growth rate among European population 2020-2100

Source: United Nations, 2019 [8]

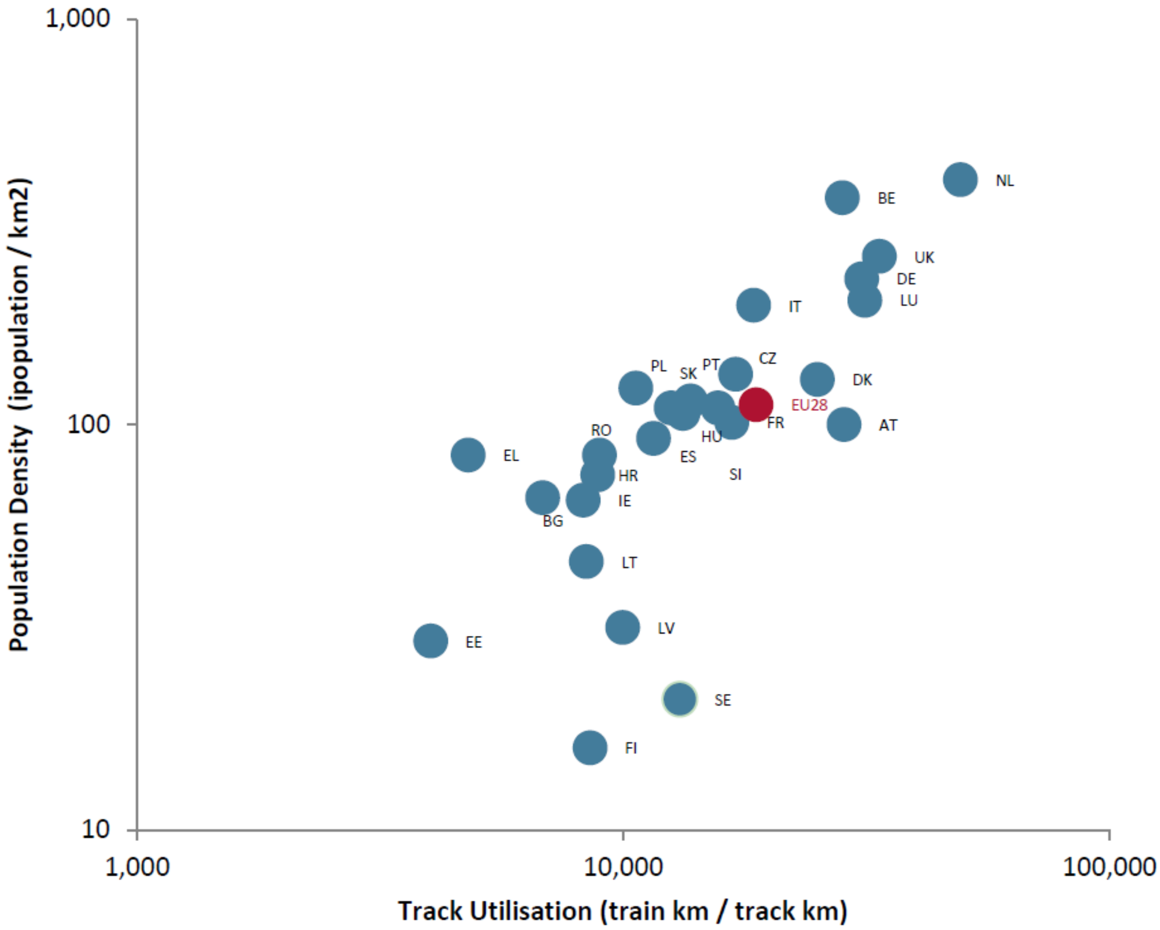


Figure 4: Relationship track utilisation and population density (2012), log scale

Source: Steer Davies Gleave, 2015, pg. 34 [4]

Likewise, the *Population change in age (ageing)* drives mobility demand. This driver is often measured by the global median age and the old-age dependency ratio (OADR) [9]. According to the OECD, "[t]he demographic old-age dependency ratio is defined as the number of individuals aged 65 and over per 100 people of working age defined as those aged between 20 and 64." ([10], pg. 122). An average OADR rate of 57 is predicted for the EU27 countries until 2100 [9]. As seen by the changing age distributions and higher OADRs for the top populated EU countries shown in Figure 5 [9], persons with reduced mobility and economical inactivity will become a large passenger segment for the future European transport system. The ageing population is already explored in the DATASET2050 project [11] [12], emphasising the importance of this demographic demand driver in earlier projects focused on intermodal, door-to-door travel. Further, the elderly have differentiated travel requirements that should be taken into account [13], [14].

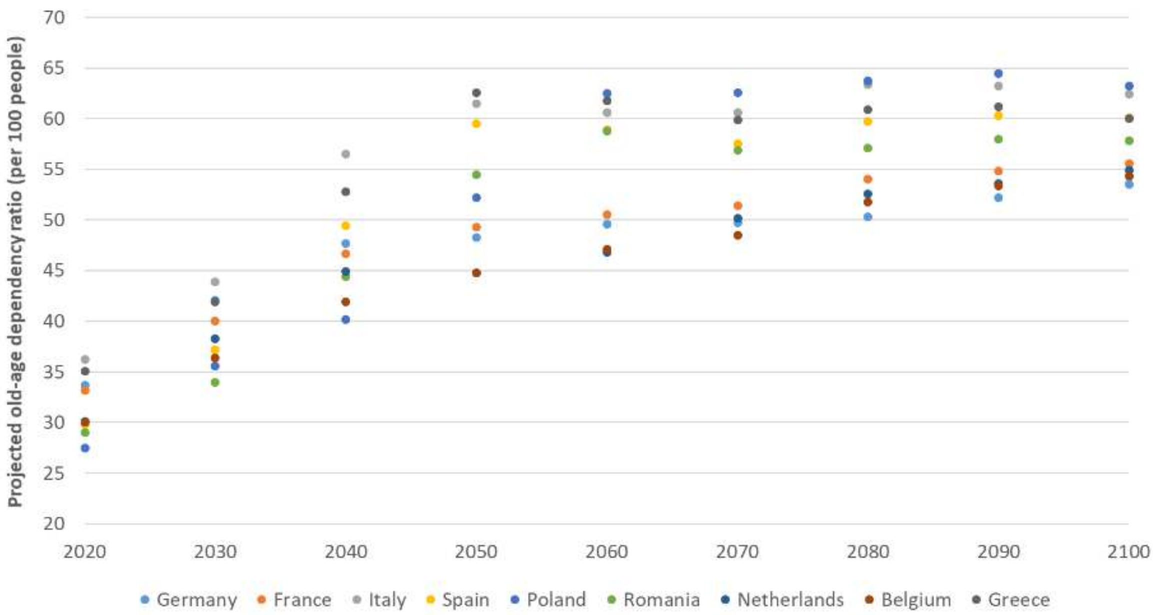


Figure 5: Projected old-age dependency ratio, highest populated countries (excl. UK) in the EU

Source: Eurostat, 2019 [9]

Other social demand drivers are *Global conflicts and terrorism*, measured for instance in number of global conflicts in a certain period and number of terrorist attacks. The literature has already shown that terrorism decreases air travel demand [15] and tourism activities in the short run [16]. According to the world's conflict map from CARTO [17], there are conflicts in many regions of the world outside the European Union, such as Africa and the Middle East. These can for instance affect *Immigration* into Europe. Esri and Peacetechlab [18] and the Global Terrorism Database [19] depict within their data maps worldwide terrorist attacks, some happened in Europe and hence, most probably also determine mobility demand in Europe. Terrorist threats can also influence aviation security measures in the transport system [20].

2.2.2 Technological (and performance) drivers

The driver *Artificial intelligence (AI)* refers to the advancement of techniques that intend to simulate human intelligence in machines, such as machine learning (ML) and deep learning (DL) models, robotics, predictive control, Internet of Things (IoT), and other implications of the large spectrum of AI. This technological driver can be measured for example in accuracy of models [21] or in computing time (e.g. sec. or min.). Both have dramatically improved within recent years. AI has a huge potential for the implementation in the public transport and aviation sector, which is explored by EUROCONTROL [22], Abduljabbar et al. [23] or substantiated with the roadmap of AI by the European Union Aviation Safety Agency [24]. Among other opportunities, AI can support the passenger's experience and multimodality within the transport system [22]. AI applications in aviation and public transport can also be used to solve pressing challenges, such as creating more environmentally-friendly transport or increasing safety [23]. Nevertheless, AI is faced with a number of challenges which the scientific community is actively researching, such as the low understanding of many AI models which are considered "black boxes", i.e. the relationship between input and output that the model obtains is not easily understood [23]; then the possible introduction of bias in the learned input-output relationship from various sources (e.g. human bias, data, model training, etc.) [21], [23], [25], legal aspects related with the protection of personal data, or ethical aspects of wider usage of AI and automation in many areas of our lives [26].

Safety, defined here as creating a safe transport system throughout for passengers [27], is included as another technical driver. It is supported through aviation security measures (not in the sense of cybersecurity) and can be measured in total number of accidents, as examined for the aviation sector by Oster et al. [20] and/ or number of fatalities [28]. Next to safety for railway and aviation, one also needs to include safety for the entire transport system including new means of transport, such as UAM [29]. More recently, safety is also driven by health concerns from the demand side: according to SABRE [30], safety within air travel might be re-defined and now include measurements against infections on board (such as social distancing in the cabin and mandatory face masks for crew and passengers). *Security-focused technologies* such as cybersecurity, block chain, biometrics and technological developments for the demand side, e.g. security, payment, and tracking, are other technical drivers on the supply side and strongly supported by AI. Automation can also support the driver *Capacity management and control systems*, which is a driver creating autonomous control on the supply side. Automated mobility and smarter traffic management are key drivers for reaching environmental targets [31]. It can be enabled through digitalisation and data sharing between modes.

Another technical driver on the supply side are *Drones and urban air mobility (UAM) systems*. Manned and unmanned vehicles, capable of taking-off and landing vertically, enable the aerial transport of people and cargo as well as aerial services for intra but also inter-urban routes [32]. The progress in that regard can be measured, for instance, in number of patents or numbers of UAM start-ups within Europe (e.g. by looking at start-up and investment databases). It is already explored as possible airport surface access and egress mode [33] as part of the door-to-door travel chain. The technical feasibility of some concepts has already been proven [34]. However, UAM companies are currently focusing on advancing the UAM technology and developing vehicle prototypes. Drones and UAM can hence not be considered a mass transport system yet and regulatory questions, infrastructure and operational aspects are still open and need to be solved before UAM services can operate [32]. Public acceptance and user adoption are often seen as main obstacles for successful UAM introduction [35] and are thus a central point of vehicle development. Especially when considering large-scale introduction of these services, air space organisation and air space management have to significantly change to enable joint airspace usage [36].

To sum up, *Drones, urban air mobility (UAM) systems*, and *Capacity management and control systems* have the potential to develop new means of transport, fostering seamless intermodal door-to-door travel within Europe. For instance, UAM and autonomous vehicles are suitable access and egress modes that benefit from safety, emissions-reduction potential, and increased comfort for the demand side.

2.2.3 Economic drivers

One key driver on transport is the *Economic growth* [5]. Indirectly, it drives transport supply via the demand levels (as explored in more detail later). The driver can be measured with the Gross Domestic Product (GDP) [37] and the GDP growth rate per country (e.g. in € or $). It is the dominant indicator for measuring the economic performance but is also viewed critically as GDP lacks to incorporate environmental and social measures [38]. It is hence of upmost importance to include supplementary drivers within analyses to balance out limitations and weaknesses of the GDP growth rates as those only show parts of a country's performance. A complementary source would be, for instance, the

Happy Planet Index (HPI) that also takes overall wellbeing, life expectancy, inequality of outcomes and the ecological footprint into account [39]. Further, as depicted in Figure 6, the GDP levels vary across European countries [37].

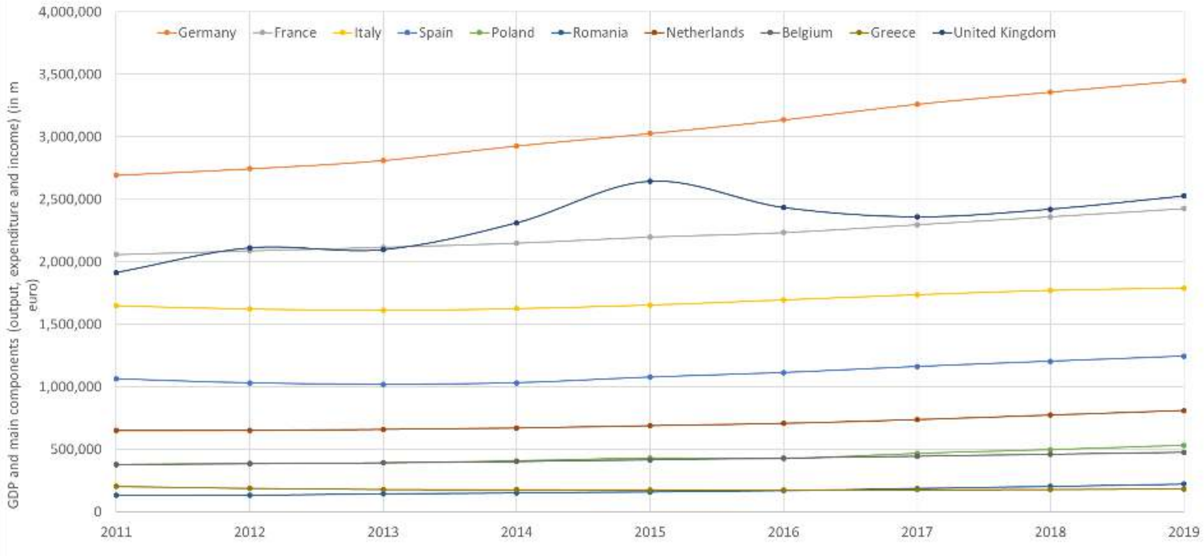
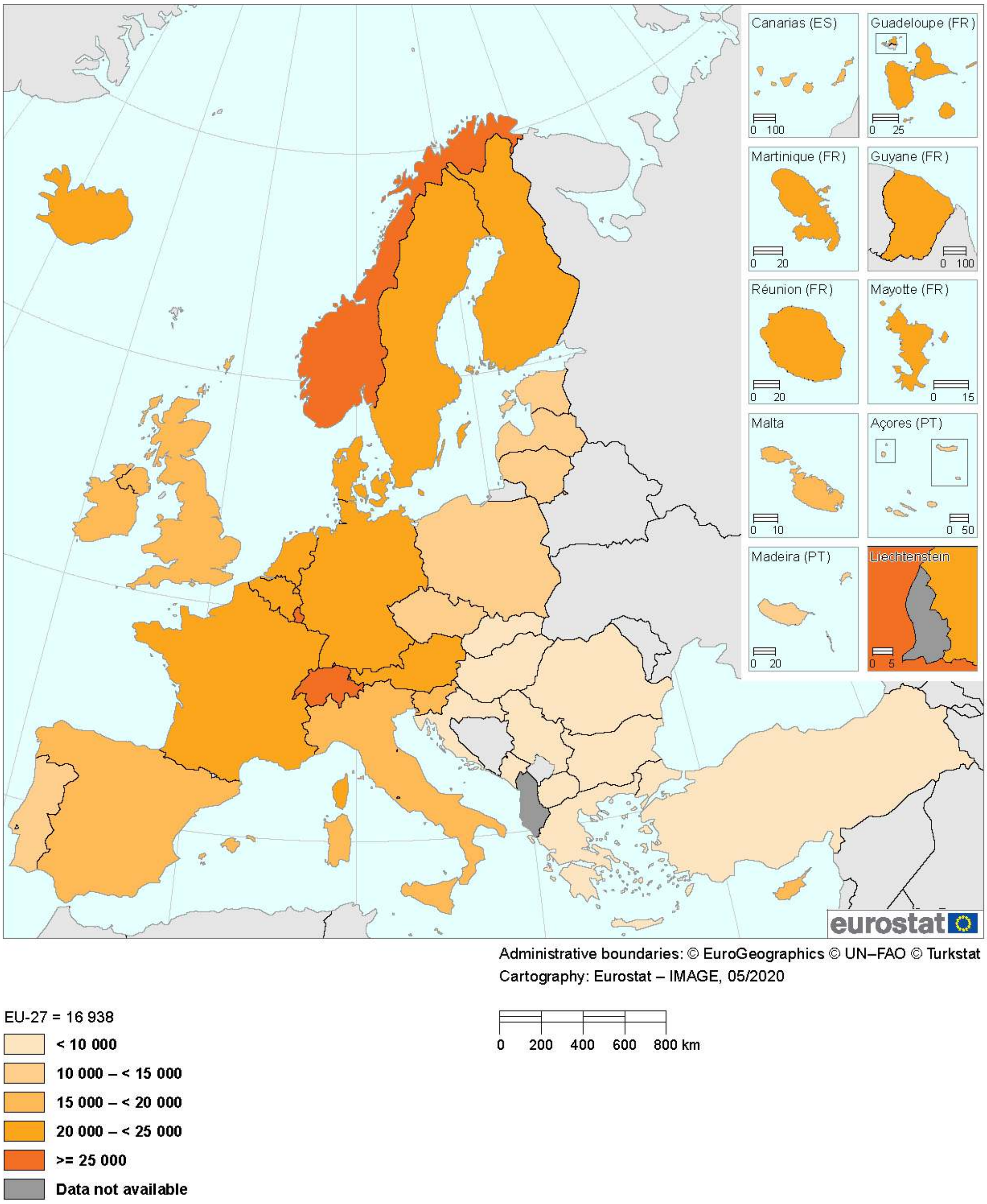


Figure 6: GDP at market prices for highest populated countries (incl. UK) in the EU, 2011-2019

Source: Eurostat [37]

In line with that, the *Change in disposable income* is identified as a key demand driver. It is for instance explored for rail travel demand in Ahern and Anandarajah [40] and Steer Davies Gleave [4] and air travel demand in Gallet and Doucouliagos [41], Kluge et al. [11] and Profilidis and Botzoris [42]. The factor is defined as increasing (or decreasing) financial resources for travel per capita and can be measured in GDP per capita (as proxy for income) but also indirectly taking the unemployment and inflation rates per city/area/country into account. Income elasticities, meaning the sensitivities of demand to changes in income, might however vary between travel markets and routes [43]. For a comparison between countries, the Purchasing Power Standards (PPS) might be a suitable measurement (see Figure 7).



Note: EU-27, estimate. Iceland: 2016. Montenegro and Turkey: 2017.
Source: Eurostat (online data code: ilc_di03)

Figure 7: Median equivalised disposable income (2018)[1]

Source: Eurostat [44]

The supply side wants to keep costs as low as possible. From an economic point of view, there are several main cost drivers, which need to be discussed here: The price of fossil energy (kerosene & diesel) and the price of non-fossil energy are two main cost drivers on the supply side [5]. Both are essential for the overall fuel price for air transport and rail transport, respectively. For instance, the fuel price is a large cost driver for airlines and over the last five years accounted for 13% - 24% of the overall costs, depending on regions, routes or aircraft type [45]. For diesel trains, energy can account for as high as 25% of all the diesel powertrain's costs [46]. Both price levels and its volatility can be measured in euro or dollars. More detailed cost drivers are discussed in the detailed analysis of supply drivers.

Further, *Evolving business models and changing market structures* within the European transport system can influence offered transport services on the supply side. The driver might refer to changing ownership structures, alliances (e.g. between airline-airline, rail-rail, airline-rail, etc.) or increasing number of mergers and alliances even cross modal. Air-rail travel products, such as RailandFly between Lufthansa and Deutsche Bahn or the airport feeder service Heathrow Express, are well established in the market. Merkert and Beck [47] show how joint ticketing for air-bus travel products can create a competitive advantage for the supply side. The increase of Low Cost Carriers (LCCs), such as easyJet or Ryanair, can be a determinant for air transport demand on certain routes [48] and it is also the case of low cost rail services as Ouigo (France), Avlo (Spain) or Flixtrain (Germany). First business model studies identify how a seat-sharing platform used by several airlines might increase the seat load factor on long-haul routes while increasing operational efficiency [49]. In fact, the mere distinction between LCCs and Full Service Network Carriers (FSNCs) seems outdated as many hybrid business models, such as global hybrid carrier or global niche market carrier, emerged within recent years [50]. This development, known as 'business model convergence' is already well explored in the air transport literature (e.g. Daft and Albers, [51], [52]). *Intermodal cooperation* and ticketing in line with the endeavour *Mobility as a Service (MaaS)* might further push evolving business models and intermodal, tailored travel products. The driver refers to mobility concepts such as integrated, single-ticketing, joint offers and pricing and multimodal transport (air-rail) including airport surface access and egress often relying on one platform (web or application) with the use of novel technology [52] [53]. Such *MaaS* services, with their strong focus on the digitalisation of travel, schedule and connectivity data and recovery services, might also trigger *Changes in reliability* on the demand side. Generally, *Reliability* refers to passengers' expectation that transport services run on time [27]. Passengers might even expect enhanced services, both for air and rail travel. This driver can be quantified as the overall number of delayed trips. Delayed trips due to traffic delays are also a product of the capacity management and scheduling of flights by the infrastructure providers, such as airports [55]. Delays are a main disrupter of intermodal, door-to-door journeys as late flights and trains have an impact on the corresponding feeder traffic to the final destination. Hence, to improve the overall transport system and increase the passengers' journey, intermodal drivers are essential.

As seen in Figure 8, Internet usage is widely spread among the top populated countries in Europe with a strong increase in the last ten years (2011 to 2019). Overall, more than 82% of the population in Europe used the Internet in 2018 [56]. In line with that proliferation and the current Covid-19-crisis, communication technologies, such as messengers (WhatsApp, Threema) and tools for videoconferencing and teleworking (Zoom, Webex, MicrosoftTeams) gain stronger momentum. The driver *Communication technologies* drives the demand side in both private and business. It can be measured in number of users or number of tools on the market. The impact of increased teleworking in post-Covid mobility needs and behaviours is an element to be studied in the future. It is currently

[1] In purchasing power standards (PPS) per inhabitant.

debatable if advanced communication tools increase or decrease passengers' demand for mobility. It might be used as substitute for in person, face-to-face meetings but pre-Covid studies show that - for instance - business air travellers do not see technology replacing personal meetings [1] and that the usage of digital media does not replace (private) interacting with other humans in person. On the other side, communication tools might also drive the demand for on-board Wi-Fi as passengers might want to stay 'always online'.

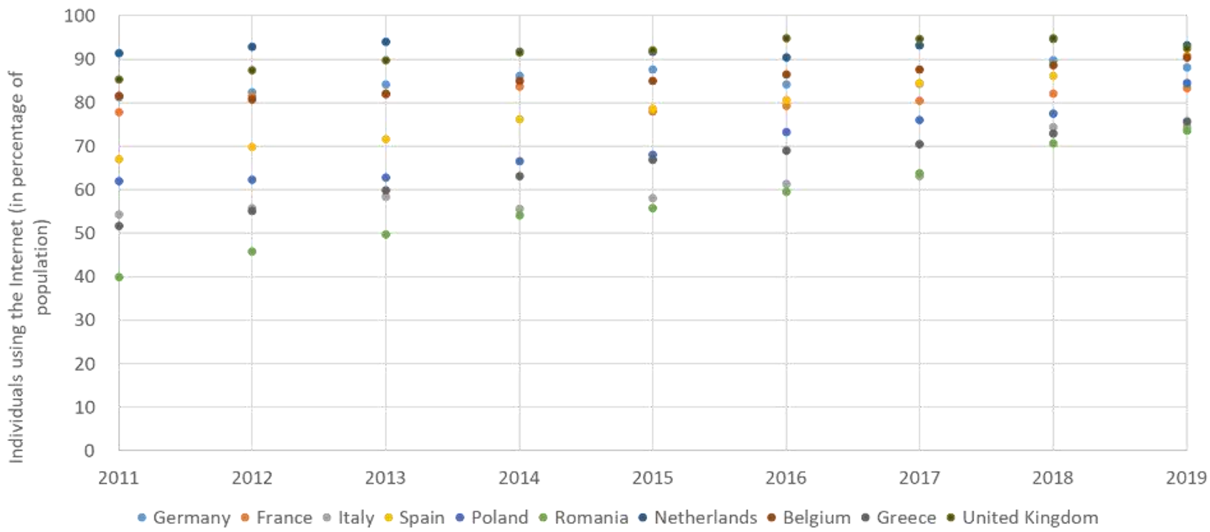


Figure 8: Individuals using the Internet among top populated countries (% of population)

Source: The World Bank [56]

2.2.4 Environmental drivers

The factor *Climate change* affects the supply side heavily. Stronger weather extremes such as heat waves and a warmer northern Europe can be strong drivers in railway and aviation operations. Climate change is not a short-winded trend but a long-term development threatening the lives in our entire world. For instance, some ecosystems are already irreversibly destroyed [57]. Until today, the last seven years were the warmest years since modern record keeping started [58]. Climate change is measurable in the temperature change rate, for instance. In fact, to "take urgent action to combat climate change and its impacts" is defined as a Sustainable Development Goal (SDG) by the United Nations ([59], pg. 50). The urgent need for action is also elaborated in the European Green Deal [60]. Climate change and actions to tackle it should affect mobility stakeholders' strategies and decision making, such as increasing operational efficiency, carbon-offsetting, and larger investment into alternative fuels and new propulsion technologies, which will be discussed below in more depth. The factor *Natural resources scarcity (NRS)* and the protection of these scarce resources might influence some of these climate actions and is another essential driver on the supply side. NRS can, also become a commercial risk [61].

In the EU, the aviation industry is responsible for around 3.6% of the overall EU28 greenhouse gas emissions (number from 2016) [62]. According to the recent report by Destination 2050 [63], zero CO_2-emissions within European aviation can be reached by 2050 via a combination of four key pillars (see Figure 9):

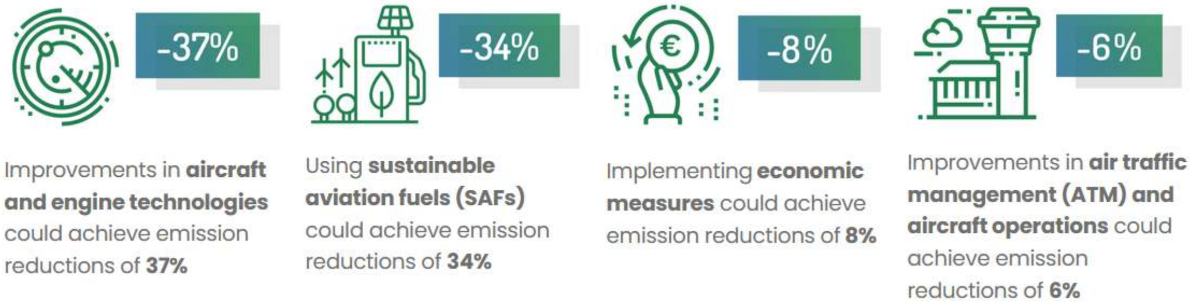


Figure 9: Combining four measures could achieve CO_2-emission reductions by 2050

Source: Destination2050 [63]

Hence, we consider *Fuels and environmental technologies* as well as *New propulsion technologies* as two essential key drivers on the supply side to tackle decarbonisation and climate change related challenges and transform aviation and railway into sustainable transport modes in the long-term. *Fuels and environmental technologies* refer to alternative fuels, liquid natural gas, hydrogen as well as the related vehicle and airframe design and operational systems. It can be measured in number of patents, the degree of Sustainable Aviation Fuels (SAF) usage, the degree of propulsion developments or engine emissions. First aircraft concept studies, which rely on hydrogen as main energy source for short-haul to long-haul routes, and with a market entry of 2035 to 2040+ already exist [64], [65]. Steinweg et al. [49] discuss an operational concept for a hydrogen-powered aircraft concept for long-haul routes. On the other hand, renewable drop-in kerosene does not require modifications to the airframe or infrastructure but is very costly and currently hardly used in the aviation industry [66]. Further, *New propulsion technologies*, such as hypersonic (air), Hyperloop (ground) or (hybrid)/ (electric) engines, can be measured in number of patents, commercial usability, market penetration and engine emissions. The electrification within aviation has been explored since the 1960s with varying maturity levels possible (types and combinations of hybrid electric aircraft vs. full-electric aircraft) and various levels of emissions, energy efficiency and reduction of noise. However, today's battery technology (regarding performance and weight) is the main challenge for the electrification within aviation [66]. First fully electric aircraft concept studies, such as the Ce-Liner, with forward-looking battery performance assumptions are already explored [67]. There are also other forms of novel engines, such as the propulsion airframe integration [68]. Figure 10 depicts the overall CO_2-reduction potential by the different drivers until 2050 to reach net zero CO_2-emissions for aviation until 2050.

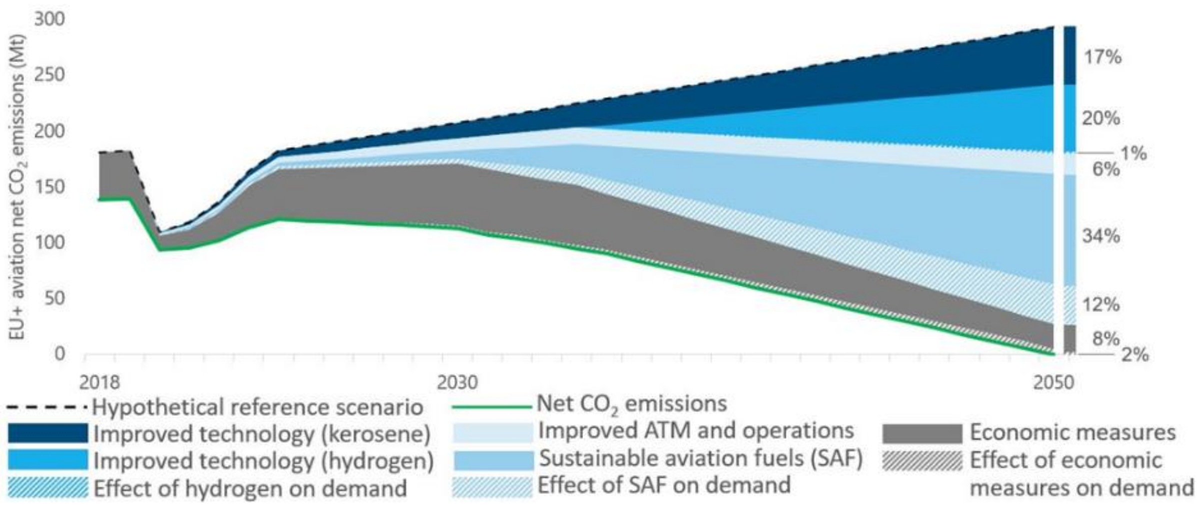


Figure 10: Decarbonisation Roadmap for European Aviation[2]

Source: Destination2050 [63]

The electrification among European railway shows a different picture. Around 75% of all passenger railway activities are based on electric trains (see Figure 11). More than 1 trillion passenger-km are covered by High Speed Rail (HSR) [69], which is the mode comparable with air transport. Railway is widely electrified and can hence be considered as playing an essential role in the decarbonisation of the transport system and can make use of renewable energy and advancements in technology [69]. It remains debatable if aviation (with the exception of UAM for short distances) will catch up with the steep electrification development within railway in just a bit more than 10 years, as shown in Figure 11.

[2] All flights in scope (all flights within and departing from the EU region). Study base year 2018.

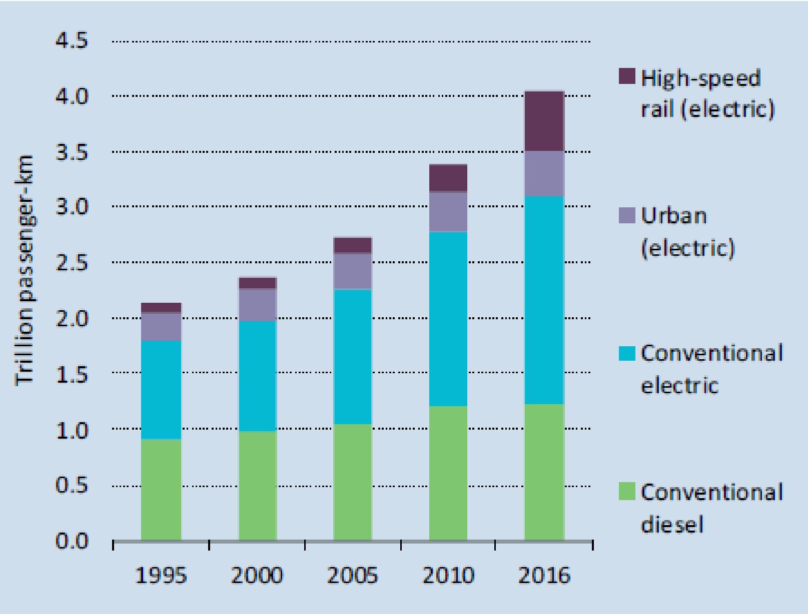


Figure 11: Rail transport activity (passenger & freight) by fuel type

Source: IEA [69]

European citizens are increasingly aware of the climate change challenge that our society is facing and are willing to act and travel in a more environmentally friendly way [70], [71]. Hence, passengers' *Environmental attitudes and willingness to change behaviour* is another identified driver for transport air and rail demand within the Modus project. It refers to passengers that exhibit increased environmental awareness and behave accordingly considering their personal actions. As shown by the second EIB climate survey results, these can be the willingness to reduce personal air travel, which 63% of surveyed European citizen have done to fight climate change. 40% of citizens have paid for carbon offsetting and 68% substitute railway for air travel for shorter trips [71]. Hence, an increase of this driver might decrease air travel demand on short-haul routes but at the same time increase rail travel demand. Next to passengers' survey data, this driver is measurable in the number of flights per year and kilometres per passenger and per capita CO_2 emissions [72]. In fact, online travel platforms already provide passengers with the calculation of their personal CO_2-emission metric per mode [73], supporting an informed and environmentally-friendly mode choice on the demand side. Mehta et al. [27] point out that choosing rail as feeder services reduces CO_2 emissions, overall congestion of the transport system and increases air quality. It is hence advised to create a transport system that encourages intermodal travel chains, e.g. by meeting passengers' need for on-time transport services, *Safety and reliability* [27].

2.2.5 Political drivers

As currently experienced due to the Covid-19 pandemic, *Travel restrictions* are in place in almost all countries around the world [74] and within the European Union (see Figure 12) [75]. This affects the transport system on both the demand and supply side. In the light of the Covid-19-related crisis, this driver gained proliferation recently but travel restrictions have also been in place pre-Covid for some long-distance routes. Travel restrictions might disrupt connections due to testing, quarantining or the entire stop of entry, making many destinations currently unattractive. Further, the demand side might also be driven by *Health concerns* and the fear of infectious disease and exposure during travel. The literature reveals concerns about possible infections pre-Covid on the passenger side [76]. Indirectly, demand side's concern might require aviation and railway players to adapt towards health and infection guidelines, such as provided by IATA [77], ECDC [78] or as addressed in the literature [79] showing once again how interconnected drivers are.

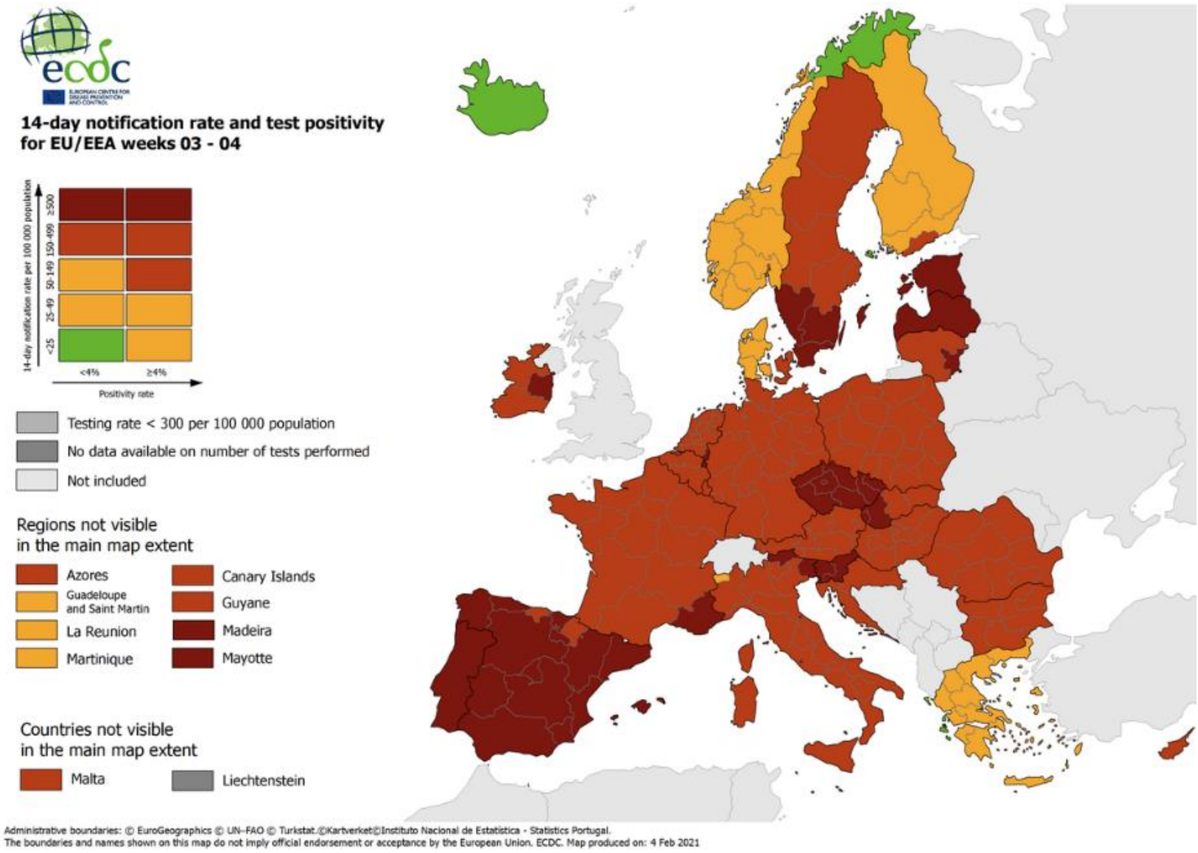


Figure 12: Covid-19 Travel Regulations Map of on 11th of February 2021 (European Union)

Source: European Union [75]

Regulatory changes on passenger rights and environmental aspects are additional key drivers on the supply side. The former aims to protect passengers against inconvenience caused by flight and rail disruptions (Regulation (EC) 261/2004 & EU Reg. 1371). Such regulations are essential for creating a passenger-centric intermodal mobility system, improving passenger services and supporting the endeavour of *MaaS*. A recent study published by the European Commission [80] explained that:

"Overall, the EU Transport policy is currently evolving to take into account the development of multimodal transport. This entails acknowledging the various dimensions and problems related to infrastructure, digitalisation, information and the protection of passenger rights. While Directive 2010/40/EU7 provided a legal framework for the development of Intelligent Transport Systems (ITS), effective information systems and collection of traffic data throughout all modes of transport, the passenger rights' acquis remains mode-specific. The mode-oriented approach of the five existing regulations can potentially lead to legal gaps and, overall, an insufficient coverage of passenger rights in a multimodal context." However, the way forward currently remains less clear, in that the authors conclude that: "[...] the analysis of impacts of policy packages remains too uncertain to support definitive findings. Therefore, as there is no guarantee that an action at European level would not hinder the development of multimodal transport today, the main conclusion that can be drawn from this analysis is that it is better to wait and monitor closely the evolution of the market in the coming years,

before taking any legislative action [...] that multimodal transport is still a niche and is not expected to increase significantly through a strengthening of passenger rights as it is suffering from other obstacles, mainly related to infrastructure at connecting points. Consequently, it is not appropriate to draw firm policy conclusions as a result of this study, given the identified limitations.”

Whilst regulations on passenger rights, such as 261/2004, increase costs for transport providers, a recent review published by the European Commission [81] also concluded that: "In general, NEBs [National Enforcement Bodies] and industry stakeholders welcome the review of Regulation 261/2004. The EC’s 2013 proposal for the revision of Regulation 261/2004 sought to balance stronger enforcement policy with economic incentives for carriers. Different aspects of this are supported by different stakeholders, depending on their perspective, but overall stakeholders that were consulted in the context of this study are keen to see the revision move forward through the legislative process."

Other passenger goals in terms of time saving might be elaborated on in agendas such as the Flightpath2050 like the 4-hours-door-to-door (4HD2D) goal, which shall support a seamless, intermodal travel chain for the demand side [82]. The latter driver sets environmental targets towards a sustainable and smart European transport system, such as the need for more multimodal and automated mobility and decarbonisation in rail and air transport [31], [60]. Figure 13 depicts the main environmental targets of the European Green Deal, which shall set the tone of European policy making and innovation actions. Such objectives can be measured in environmental targets for reducing CO_2 and non-CO_2 emissions (target of 90% CO_2 emissions reduction by 2050 as elaborated in [60], pg. 10 - 11, 2.1.5) and environmental targets in % of noise reduction (airports and railway stations).

Figure 13: The European Green Deal

Source: European Commission [60]

Trade policies (globalisation) refers to trade agreements and trade barriers between regions and countries. These might increase or decrease the transport (and freight) demand and can be quantified with the KOF Index of Globalisation [83]. There is a database available for comparisons on a country level: the KOF Globalisation Index from the ETH Zurich [84] can measure political, social and economic dimensions of this driver.

2.2.6 Mobility-related drivers

Travel profiles are increasingly differentiated creating *Diverse travel needs and personalisation* along the entire travel chain [85]–[87]. Ketter [88] shows for instance how the digitally-savvy Generation Y (also known as Gen Y) changes regarding their travel behaviour compared to former generations, and are hence shaping novel tourism trends such as 'creative tourism' for personal and unique experience building. As already explored above, the European population is ageing and thus a larger share of the ‘best ager travellers’ generation will emerge. Further, the DATASET2050 [2] project developed a range of changing current and new future passenger profiles [11], [12]. It can be assumed that tourism is also likely to change as a demand-side driver. Such *Change in tourism pattern* might be the creative tourism, or the rejection of mass tourism towards more niche tourism, also due to restriction of places of interests. In light of the current Covid-19 pandemic, virtual tourism (also known as digital tourism) is also gaining momentum [89]. The supply side needs to adapt to such passenger trends. Another mobility-related demand driver is the travel purpose, referring to the question if a passenger is travelling for business or leisure purposes. The UNWTO subdivides private travel further into the categories: visiting friends and relatives (VFR), health, religion, leisure, recreation and holidays and others. Business travellers are less price sensitive than leisure travellers [90]. Conversely, studies also show that both travel purposes can also be merged to ‘bleisure’ travel (business and leisure travel), especially among the younger generation of business travellers [1]. Further, Gössling et al. [91] elaborate within a recent study how air travel developed towards a social norm which implies that large parts of society travel by air (pre-Covid). In fact, this is not the case as inequality of air travel trips is observable in many European countries depending on financial resources (*Disposable income*) and other constraints [91]. Gössling et al. point out that air travel trips might have different levels of importance, hence providing much room to decrease personal air travel to support the decarbonisation and relief of the transport system in times of high utilisation.

2.3 Demand drivers – detailed overview

While transport demand is mainly explained by the price-time ratio, we wanted to improve our understanding of this demand. To do this, we sought to identify as many potential determinants of demand as possible. We have therefore carried out a very broad review of the literature, focusing on the traditionally known determinants, but also on others that are less well known. This work focuses initially on the determinants of supply that have an effect on user demand. Following that, we will study transport demand through the individual characteristics of users and finally through psychological and sociological representations.

In the remainder of this section, we will therefore describe and analyse the determinants of demand by family in order to define them in relation to the object of our study.

Table 1: The objective characteristics of transport supply

STEEP-M	Driver name	Source	Definition	Indicators
Mobility	Transport time	[92]–[94]	Travel time between origin and destination. Corresponds to travel time, waiting time,	Duration in minutes Value of time in euro per hour

STEEP-M	Driver name	Source	Definition	Indicators
			upstream/downstream transit and connection time	
Mobility	Reliability	[95], [96]	Ability of the transport system to deliver the expected quality of service on which users have organised their activities	Time range Frequency level Delay rate Cancellation rate
Mobility	Accessibility	[97], [98]	Easiness to access to a specific location (home, work, infrastructure, etc.) from another location	Access time Distance Price Mode of transport
Technological	Safety	[99]	Prevention of material and personal accidents/incidents. Refers to protection against accidental events.	Number of incident/accident per travelled kilometre Number of incident/accident per 1000 travellers
Technological	Security	[99]	Prevention of malicious acts against people, materials and infrastructure. Refers to protection against intentional events.	Cost of malicious acts per year Number of malicious acts
Mobility	Connection	[100], [101]	A connection is defined as a change in transport mode or line.	Number of connections Time of connections Distance of connections
Technological	Connectivity	[92], [100], [102], [103]	Ability to connect to one or more networks (mobile internet, Wi-Fi, telephone network)	Access to : Mobile internet (4G) Wi-Fi Telephone network
Mobility	Interoperability	[104]	ability to communicate and exchange with one or more other ticketing systems	Number of common interfaces Number of ticketing system
Technological	Information	[105]–[107]	Ability to produce information and deliver it to users	Number of dissemination channels Average time taken for it to be disseminated and made available to users

The first determinant is *Transport time*. This is widely discussed in the scientific literature. *Transport time* is a key variable affecting transport demand according to several authors, like for example Dickmann [108]. According to him, "minimisation of travel time is the main factor behind modal practices". This approach implies that travel time is a variable to be minimised, as travel time is considered to be an inconvenience. Crozet [93] agrees with the approach adopted by Dickmann and complements it by relying on the value of time and the generalised cost of transport. The generalised cost of transport is a concept based on the work of Becker [92] on the consumer utility function. The generalised cost of transport is the monetary and non-monetary sum of transport. It is expressed as:

$$Cg_{i,t} = P_t + h_i \times D_t$$

Where *t* is the mode of transport, *i* the individual, *P* the price of transport, *h* the value of time and *D* the duration. Reducing transport time is a solution for Becker to reduce the generalised cost of transport.

The generalised cost of transport therefore incorporates the value of customer's time, which means that this cost varies from one individual to another. This cost variability is one of the reasons for modal choice [93]. *Transport time* is an intermediate consumption to be reduced as much as possible. Nevertheless, it now appears that minimising *Transport time* is no longer a factor explaining modal practices [94]. Indeed, the emergence of ICTs has so much to do with transforming transport time from 'wasted time' to productive and therefore 'useful' time. As a result, the modal choice is no longer motivated solely by the reduction of transport time, but also by the maximisation of productive time. For example, the train is more in line with the quest to maximise productive time than the aeroplane, because it offers a less fragmented transport time. Other factors can also be added to the explanation of modal practices such as comfort, reliability, etc.

The second determinant is *Reliability*, which is defined by the OECD in 2010 as "the ability of the transport system to deliver the expected quality of service on which users have organised their activities". According to de Palma et al. [95] *Reliability* is a determinant of transport demand that includes different notions. One of these notions is predictability, the ability to predict a travel in advance, i.e. before it takes place. This first notion is completed by punctuality. Punctuality consists of being on time. This notion reinforces the ability to predict transport. Finally, the last notion is the absence of human and/or material failure. This reinforces the confidence index of transport reliability. These different notions are interdependent with each other [96]. Their aggregation allows us to translate the broader concept of reliability. Several indicators for measuring the reliability of a transport system include frequency, hourly amplitude or the rate of delays or cancellations. However, these indicators only allow the reliability of a transport system or network to be assessed, as there may still be considerable heterogeneity within it. The reliability of a network is an average value estimated on the basis of the reliability of each origin-destination carried out on the network, i.e. at all hours and periods (day, week, month and year). As a result, network reliability is represented by an average value and is therefore not necessarily representative of reality. For example, reliability may vary widely from one line to another, but also from one period to another (off-peak vs. peak time, day worked vs. day not worked, etc.). There may therefore be a heterogeneity of reliability within a network.

The third attribute of transport supply is *Accessibility*. This attribute reflects the easiness to access to a specific location (home, work, infrastructure, etc.) from another location [97], [98]. This determinant then makes it possible to translate the difficulty for a given individual to reach a desired destination. There are several variables that can be used to measure accessibility, such as time, distance, cost or mode of transport. Among these variables, time is considered the most appropriate variable to account for accessibility.

The review of the literature proceeds with *Safety and security*. These two determinants are complementary in our analysis. The first concerns the prevention and protection of accidental events, while the second deals with intentional events. There is a consensus in the literature on the impossibility to measure these two determinants. However, there are different methods for estimating them. One example is the work carried out by Jones-Lee [99] comparing the theoretical approach for estimating safety using two methods, namely 'loss of production' and 'willingness to pay'. *Safety and security* are also estimated by the method 'cost-benefit analysis' for investment projects.

In addition to this, *Connections* are a very important determinant of transport supply. A connection is defined as a change in transport mode or line. It results in a split of the journey for the user. In the literature, connections are negatively connoted [100] and cause additional uncertainty. This is translated economically in the Quinet report of 2013 where the transfer time is weighted by a multiplying factor in equivalent minutes. There are several indicators, such as the number, time or distance of connections that make it possible to apprehend this interruption in the movement of individuals as described by Hubert et al. [101].

Interoperability is a key determinant of transport demand. According to Couénon and Janin [104], it lies in the "ability to communicate and exchange with one or more other ticketing systems". According to Couénon and Janin [104] , interoperability allows the user of a transport network "to free himself from the limits of networks by using a single ticket medium". This concept represents a major challenge, as it makes travel easier for users by simplifying payment for the various modes of transport using a single ticket. There are several examples of consortiums around the world fostering interoperability by using one single card for different modes of transport, e.g. commuter and regional trains, bus, metro and bike/car sharing in Paris area (France). There are some indicators to measure the degree of interoperability, such as the number of titles or common interfaces. It can also be measured by its level of ticketing compatibility.

Connectivity in transport represents an emerging element in transport demand. Connectivity in transport is characterised as the ability to connect to one or more networks (mobile internet, Wi-Fi, telephone network). Connectivity, beyond simple Internet and telephone networks, corresponds to the availability and compatibility of these different networks in the quantity and quality necessary to carry out usual activities, such as Wi-Fi or 4G network. In addition to this, electrical connectivity with the availability of mains or USB power sockets. We consider that connectivity is a factor that enables users to make "productive use of travel time" [103] by facilitating the appropriation of this time through tools used on a daily basis [102]. Thus, the interpretation of travel time as intermediate consumption [92] is partly challenged by user connectivity and the analysis of Mokhtarian et al. [103].

Concluding this first category of supply attributes is the driver of *Information*. The ability to produce information and deliver it to users is important because it acts as a facilitator of travel [106], [107]. It also improves the predictability of transport for the user by providing access to information. This direct time access also acts as a decision aid in the event of disruptions or modal choice [105]. It is complicated to obtain indicators to measure the information itself. The indicators that are available make it more possible to measure access to information, such as the number of dissemination channels or the average time taken for it to be disseminated and made available to users.

Table 2: Individual characteristics of users

STEEP-M	Driver name	Source	Definition	Indicators
Social	Individual and socio-economic characteristics of travellers	[109]	Criteria that define an individual	Age, gender, socio-professional category or salary
Social	Motive of travel	[90], [110]	Different reasons for travelling	Motive of the travel (tourism, visit to family or friends, business, etc.) Length of the stay at destination
Social	Additional burden	[101]	Additional burden and/or liability when travellers are accompanied by dependent or partially dependent people	Number of non-autonomous people per chaperone
Social	Values	[111]	Belief or adherence that can change our relation to modes of transport.	Values of ecological awareness
Social	Individual and socio-economic characteristics of travellers	[109]	Criteria that define an individual	Age, gender, socio-professional category or salary

In addition to these supply drivers, the following describes drivers for demand in modal choice.

Starting with the *Individual and socio-economic characteristics of travellers*, this determinant groups together the criteria that define an individual. Among these criteria, we have age, gender, socio-professional category or salary. The influence of these characteristics has been studied by Madhuwanthi et al. [109].

The second determinant concerns the *Motive of the travel* that has been extensively studied in the literature and has been proven to influence transport demand. Much research on this topic shows that the motive influences transport demand. The different reasons for travelling are not associated with the same constraints such as time or travel budget. Thus, the demand for transport varies according to these constraints. For example, business travel has a lower price sensitivity than leisure travel [90]. To demonstrate this, Brons et al. use the price elasticity of travellers by reason for travel. The reason to travel can also influence traveller's needs. Marchand and Weiss [110] show that individuals travelling for business purposes are more demanding of comfort and space in order to make the most of their travel time.

The next determinant relates to the notion of additional *Burden* and/or liability. Modal practices and travel strategies differ if travellers are accompanied by dependent or partially dependent people, such as children or people with physical or mental disabilities [101]. We also already explored in the high-level overview special travel needs of the elderly. These same strategies or modal choices also depend on the number, volume or weight of luggage to be transported. There is no indicator to represent this determinant, as the additional burden or responsibility will not carry the same weight between individuals, and the habit or physical condition of each individual will play a role in the burden it represents. Nevertheless, we can use the number of non-autonomous people per chaperone to reflect responsibility. With regard to the load, the weight of the luggage will be used to express the additional load.

Concluding this second family of determinants are *Values*. These are defined as a belief or adherence that can change our relation to modes of transport. Gössling et al. [111] study the 'flight shaming' movement. Through this study, they show that people who are aware of and believe in the harmful role of air transport on the environment are more reluctant to use the air transport for their travel. We can, for example, speak for the values of ecological awareness.

Table 3: Psychological and sociological representations

STEEP-M	Driver name	Source	Definition	Indicators
Social	Perceived transport time	[112] [113]	Way in which time is experienced	Duration in minutes
Social	Perceived comfort	[112], [114], [115]	Way in which travelling comfort is experienced	Weather, temperature, noise, available space, service on board and predictability
Social	Perceived Control	[100], [100], [110]	Perception of contingency between behaviour and its outcome	Information, level of stress, quality of the environment and crowds
Social	Perceived safety	[116], [117]	Factor that generates a feeling of discomfort when it is of moderate intensity and can even reach modification when the intensity is high	Quality of the equipment and cleanliness
Social	Perceived security	[118]	Perception of unsafe travel	Geopolitical (terrorism, etc.), cultural or technological context
Social	Perceived information	[105]	Perception of reliability and confidence level in provided information	Reliability, relevancy, understanding and access of the information
Social	Perceived reliability	[119]	Perception of the reliability in the experience lived when travelling	level of confidence about the reliability and past experience

We have just detailed the determinants corresponding to the individual characteristics of travellers. Through these different characteristics, we have just studied their potential influence on the demand for transport.

To conclude this review of the literature, in the next section we observe the role of psychological and sociological representations on transport demand. In this last family of determinants, we return to the previously mentioned determinants, but with a different approach. Indeed, we will focus on the way individuals perceive these determinants and how the way they perceive these determinants can modify transport demand. Therefore, we will focus here mainly on the psychological and sociological aspects of individuals.

Perceived transport time refers to the way in which time is experienced. This perception will mainly depend on several criteria such as comfort, occupation and information [112]. Further, boredom increases the perceived travel time compared to real time [113].

Perceived comfort is the second determinant that can influence transport demand and modal practice, by modal practice we mean the choice and use of a mode of transport. Comfort is a rather fuzzy notion, as it depends on individuals, however [112], based on work by [115], finds that comfort is a notion that is assessed through a process of comparison and therefore by its opposite, which is the feeling of discomfort. This notion is based on multiple criteria such as weather, temperature, noise, available space and predictability [114].

Control is defined as the perception of contingency between behaviour and its outcome [110]. In other words, the information is a tool for the traveller to inform him about the conditions of his journey's progress (time, place of departure and arrival, itinerary, delays, accidents etc.) but also on the different alternatives for getting around (itineraries, means of transport, prices, etc.). This information tool helps to reduce the distortion between the behaviour adopted by the traveller and the result desired by the traveller. The feeling of control is a determinant that will play a role in influencing different perceptions of the traveller. Depending on the user's level, this feeling will enable him or her to feel more or less uncomfortable. There are several variables that allow the individual to achieve a good level of comfort. The main variable is information, which allows the user to adopt his or her behaviour according to the desired result. Information reduces uncertainty [100].

Perceived safety in transport is a factor that generates a feeling of discomfort when it is of moderate intensity and can even reach modification when the intensity is high. This change in behaviour will be characterized by a search for safer mobility, with different modal practices depending on the perceived risk [117] . It is also noted that the perception of risk may be increased by certain individual characteristics such as gender [116].

Perceived security influences modal practices, as individuals perceiving a mode of transport as unsafe are going to seek to find other mobility alternatives [118]. Several elements are likely to increase perceived safety, such as the geopolitical (terrorism, etc.), cultural or technological context.

The *Information perceived* by users depends on its reliability and the level of confidence in it [105]. Perceived information will mainly affect the perception of other determinants such as the perceived of control or comfort.

Concerning *Perceived reliability*, there is a great variability between actual reliability and its perception [119]. Indeed, the perception of reliability is based on the experience lived at specific times and destinations. This perceived reliability is all the stronger when the recurrence is high. Constraints linked to travel (appointments, etc.) can accentuate the perception of reliability.

2.4 Supply drivers – detailed overview

Supply drivers are factors that influence the characteristics of transport supply in a network. In other words, they are the motivations for stakeholders playing a role in the provision of transport services (e.g. transport operators, infrastructure operators, mobility service providers, etc.). This section has the goal to deliver a compact, comprehensive list of supply drivers and indicators that can be used for modelling purposes.

Supply drivers are in many cases influenced by travellers' expectations and behaviours, which in turn affect supplier decisions on the provision of transportation and mobility services. In a market economy, supply is explained in relation to demand, and vice versa. Thus, it is critical to establish a link between supply and demand (modal choice) drivers when it exists. On the other side, other supply drivers can be defined as exogenous, i.e. generated by causes outside of the transport network, and affecting the overall network instead of specific modal transport networks. These are related to constraints by the regulatory and operational context, or by global shifts in demand, and are not directly driven by specific modal demand drivers.

The macro/micro level classification used in the demand drivers is arguably unusable for the classification of supply drivers, since these are all defined at network level (i.e. macro) and not at the passenger decision level (micro). Supply drivers affect transport supplier decisions, and are not directly affected by a specific passenger's modal choice. It is proposed instead to organize the supply drivers in two categories based on the classification outlined above (Figure 14):

- Exogenous: These drivers are contextual, generated outside the overall transport network, and affect mobility supply as a whole. Indicators for these supply drivers are defined independently of the transport mode used.
- Endogenous: These drivers are generated inside the transport network, and affect transportation modes differently. They represent differentiating factors across modes, and can be used to explain advantages and disadvantages of a specific mode over others. Indicators can also be measured differently depending on the mode.

The supply driver classification below is based on DATASET2050 [2] and additional drivers based on new trends found on literature research and in the expert survey results.

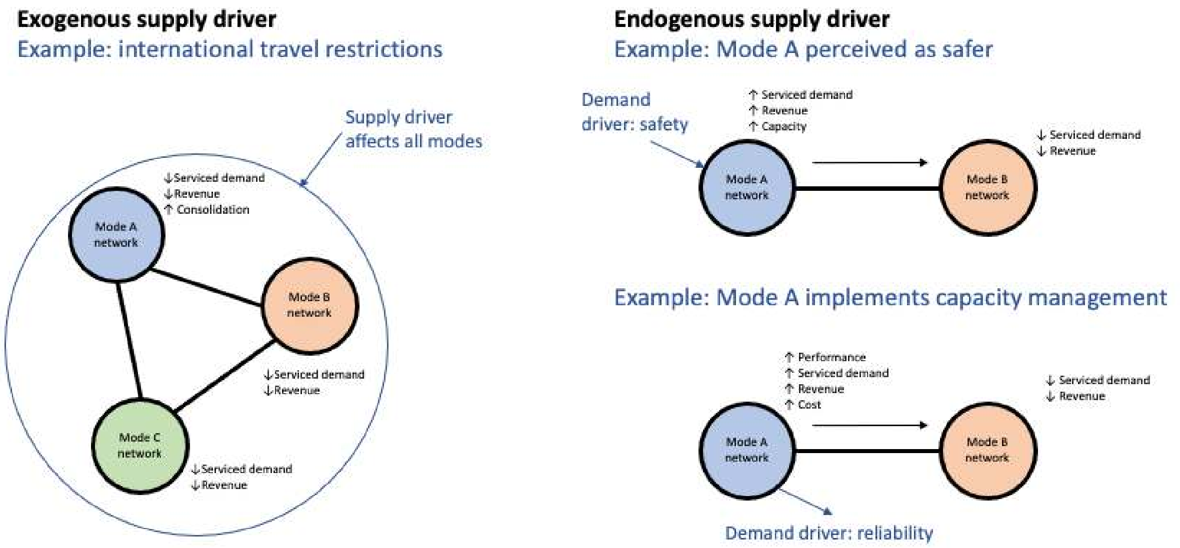


Figure 14: Exogenous & endogenous supply drivers, impact across modal transport networks
Source: own depiction

Table 4: Exogenous supply drivers

STEEP-M	Driver name	Definition	Indicators	Data
Social / Economic	Development level	Capacity of a catchment area to sustain economic growth and well-being of its population. Catchment areas in this scope are geographical areas that can be generate potential travellers at local, regional, national or international levels. This driver affects the overall demand curve, which in turn makes the supply curve shift to reach equilibrium. This type of factor corresponds to the traffic/demand group defined by Paul et al. (2018) in DATASET2050 D4.2, specifically social well-being, middle class development, and consumer demand. Macroeconomic factors representing purchase power and GDP within a geographic area are also included here, all of which have a positive impact on the demand of travel.	Gross Domestic Product (GDP) - may be refined as social and environmental indices as proposed by Giannetti et al. (2015) GDP per capita, disposable income and income inequality Human Development Index (HDI) Middle class development indicators	[8], [37], [37]
Social	Geographical distribution of travellers	This driver represents patterns of distribution in the population volume, density and demographics in a catchment area. This driver affects the demand curve for particular geographical areas and population segments, which in turn makes the supply curve shift to reach equilibrium. These factors also belong to the traffic/demand group as defined in DATASET2050, with the different that they can be measured not only as macro level figures, but within a regional or local area (and often represented as heat maps across a geographic area). They are usually complex combinations of factors that define traveller's behaviours, which can also depend on non-measurable factors such as culture. Thus, the best way to represent these is as distribution of traveller archetypes - a classification of the future passenger profiles in 2035 was made by Paul et al. (2016) in DATASET2050 D3.1 based on traveller goals, similar to the classification made by the Future Foundation (2015). Siren and Haustein (2013, 2015) and Ketter (2020) use generational classifications to define traveller behaviours.	Population volume, density, growth and migration trends Urbanisation rate Distribution of traveller archetypes (age, gender, socioeconomic class, household structure, education level, culture and habits)	[6], [9], [56], [120]
Environmental	Environmental awareness	This driver represents the impact of environmental effects of transport and the global economy, together with reactions to them from public institutions (environmental regulations) and the society in general	Global CO_2 tons, may be geographically allocated, as studied by Graver et al.	[58], [71], [73], [121]–[123]

STEEP-M	Driver name	Definition	Indicators	Data
		(environmental awareness and commitment to act from the part of citizens). Attitudes and actions towards climate change by EU citizens was studied by the European Commission (2019) and the European Investment Fund (2020), which includes conscious transport choices to reduce emissions. However, environmentally oriented choices by travellers are a trade-off with higher cost, as has been studied by Pearce (2008). Thus, this driver affects the overall demand curve, which in turn makes the supply curve shift.	(2019) for aviation emissions CO_2 tons per capita Global year temperature change Environmental Performance Indicator	
Economic / Political	Market openness	In a market economy, openness measured as the lack of barriers to execute business initiatives for economic growth, is a critical factor. This driver consolidates facilitators and barriers to do business in a transportation market concerning: Regulations and public support on the management of transportation services within domestic markets, including business activity restrictions due to Covid-19. Regulations on passenger rights is another factor influencing the supply. The current status of air passenger rights has recently been explored by Kouris (2020). Regulations governing the mobility of passengers and good across international borders, including border travel restrictions due to Covid-19. Degree of innovation, which promotes international R&D cooperation and institutional support for the development and implementation of new technologies improving environmental, efficiency or convenience factors. Rule of law, or degree of governance quality in a political system, as measured by Worldwide Governance Indicators. Geopolitical stability, measured as lack of unexpected legal framework changes or violent conflicts, such as terrorist attacks, studied by Liu and Pratt (2017) and Ito and Lee (2005).	Ease of doing business index International trade indicator Travel restrictions Worldwide Governance Indicators	[17], [18], [124]–[129]

Table 5: Endogenous supply drivers

STEEP-M	Driver name	Definition	Indicators	Data
Economic	Available infrastructure capacity	Infrastructure capacity is the maximum demand that a modal transportation network can service, expressed in terms of maximum sustained demand (absolute), or additional sustained demand (relative to current). This driver quantifies how much demand can be added to the existing network cost-efficiently, but also how much spare capacity there is and thus how inefficient the current infrastructure is. Changes in available infrastructure capacity can be caused by infrastructure expansion, or by reduction of the serviced demand. It allows comparison of infrastructure capacity between alternatives (e.g. air and rail).	Available seat km (ASK), airport capacity Spare infrastructure capacity = 1 - Load factor (1 - RPK/ASK) Length of railway tracks Length and density of motorways, number of passenger cars (motorization rate) Aircraft or vehicle capacity	[74], [130]–[134]
Social / Economic	Serviced demand	This driver represents the current volume of demand that a modal transportation network is servicing, together with growth and seasonality trends. This driver characterises the demand that the network is confronting, and allows one to identify if there is a risk of not being able to service the demand level at its equilibrium point. Changes in this driver, represented by a shift in the demand curve for a specific transportation mode, can be caused by: • Global changes in the demand (see exogenous supply drivers) Changes in the demand of other complementary/supplementary transportation modes. In this case, this driver is a consolidation of the impact that shifts in modal choices (see demand drivers) have on a specific transportation mode.	Revenue passenger km (RPK) Railway passenger km Road passenger km Load factor (RPK/ASK, rail passenger km/rail km, road passenger km/road km)	[74], [130]–[134]
Economic	Operating costs	This driver represents the costs of operating a modal transportation service, usually measured as unitary costs per traveller capacity. Operating costs include: • Use of infrastructure (e.g. fees) • Energy / fuel	€ / ASK € / rail km, € / road km	[74], [130]–[134]

STEEP-M	Driver name	Definition	Indicators	Data
		• Fleet • Supply chain • Labour Changes in this driver are usually caused by changes in regulations, or by innovation (e.g. automation, Artificial Intelligence, capacity management and control, etc.). This driver allows one to compare supply cost efficiency between modal alternatives.		
Economic	Operating revenues and profit	This driver represents the efficiency of a specific modal transportation network to convert demand into revenue and profit. It is usually measured as unitary revenue and profit per carried traveller. Changes in operating revenue and profit may be caused by changes in the operating cost, which in turn have an effect on the end price for traveller and the demand. Price elasticity of demand often plays an important role in quantifying the effect of this driver.	€ / RPK (revenue per passenger) (€ (revenue) - € (cost))/ RPK (profit per passenger)	[74], [130]–[134]
Economic	Rigidity	Rigidity is a quantification of barriers to introduce flexible intermodal integration and personalisation. Initiatives and new business models such as ticket interlining, multimodal ticketing, Open Data, and MaaS, are being introduced to remove these barriers and increase travel flexibility. Rigidity can be measured from the supply point of view in terms of cost to reallocate a passenger journey across schedules and across routes, including complementary modal choices.	Cost (€) of passenger reschedule Cost (€) of route reconfiguration	No reference data has been found.
Environmental	Carbon footprint	This driver quantifies the emissions impact of the utilisation of a specific modal transport service. It is usually measured in emissions per unit of traveller and distance, and allows one to compare the performance in terms of emission reduction among transportation modes. This driver is generally driven by availability of energy-efficient technologies such as new fuel and propulsion systems, which reduce the emissions amount of the transportation service. This	CO_2 tons / passenger km CO_2 kg/passenger/leg	[69], [73], [135], [136]

STEEP-M	Driver name	Definition	Indicators	Data
		corresponds to some of the high-level factors identified in DATASET2050 D4.2: green innovation, and emissions.		
Economic / Technological	Safety and convenience	This driver quantifies the performance of a specific transportation mode in aspects influencing the quality and safety of the travel experience. These aspects can be: • Travel time • Comfort • Amenities • Safety and security Safety and convenience are generally driven by the availability of new technologies and designs (e.g. propulsion systems, health safety screening, efficient security screening, wireless connectivity, cabin designs, etc.). This corresponds to some of the high-level factors identified in DATASET2050 D4.2: innovation, ICT technologies, global R&D collaboration, and international cooperation.	Speed flown (aircraft kilometres / airborne hours) Average block speed (aircraft kilometres / block hours) Rail speed Passenger travel time Passenger data connectivity Transport comfort index	No reference data has been found.
Economic	Market structure	This driver represents the institutional structure of transportation suppliers in a market. In this scope, a market can be defined among suppliers of the same transportation mode (e.g. European-wide long distance high-speed rail) or among transportation modes (e.g. air and rail transportation between Brussels and Vienna). This driver helps explain expected behaviours of suppliers, depending on the degree of consolidation vs competitiveness the industry is in the spectrum. A higher consolidation translates into lower buyer bargaining power and higher supplier influence.	Number of suppliers Market share	[74], [137], [138]

3 Modus Expert Survey

3.1 Introduction

The purpose of the questionnaire is to capture the expertise of various experts from different transport sectors with regard to possible futures for European travellers and factors with the most influence on the evolution of travel. The survey provides inputs to the Modus project about future transport drivers, for modelling and simulating future transport performance and building informed recommendations to decision-makers.

The questionnaire is concerned with supply and demand drivers relating to the door-to-door (D2D) travel chain, including air and rail travel, in 2040 (both in the context of business and leisure trips). We would like to take a long-term perspective of European travellers (cargo is not within scope). The focus is on multimodal transport that includes as a main segment either rail or air transport. Other transport modes such as public transport are considered as access and egress modes (feeder traffic) to either the airport or the rail station. The focus is on travel segments within Europe as part of a multimodal journey, e.g. a passenger journey from Paris to Berlin, or from Helsinki to Lisbon. The following Figure 15 shows the progress of collecting data through conducting the expert survey. Each step is described in detail in the following chapters. The complete survey are included in the Appendix B.

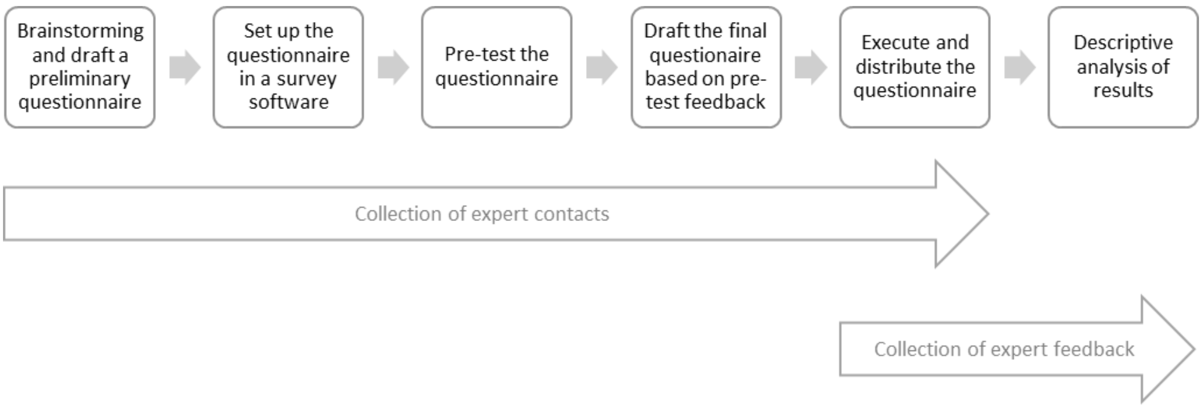


Figure 15: Graphical abstract of the implementation of the Modus survey

Source: own depiction

3.2 Brainstorming and preparation

To understand mainly the supply and demand drivers for air, rail, and combined air-rail transport by 2040, as well as the long-term impact of Covid-19 on future demand and supply of air and rail transport in Europe, we drafted a first version of the questionnaire based on the conducted high-level literature review and several rounds of brainstorming within the consortium.

To ensure the diversity of professional domains and expertise, we have collected more than 50 contacts of subject matter experts mainly from aviation and rail industries (including academia) based in Europe. We approached the experts and received feedback regarding whether they are interested in participating in the survey and the "The Future of Multimodal Transport: Horizon 2040" workshop, which was conducted online in January. We made an attempt to contact and approach experts through the entire survey process.

3.3 Survey setup and pre-test

The preliminary questionnaire was then set up using the survey tool SurveyMonkey (https://www.surveymonkey.com/) with a paid plan, which allows some advanced survey builder features such as 'matrix of drop-down menus'. A pre-test of the questionnaire was conducted mainly within the consortium and a few external colleagues (these were not part of the expert sample). Besides providing feedback concerning the contents of the survey, we asked the pre-test participants to indicate the time they spent to complete the survey and rate the survey quality. Based on the feedback gathered from a few responses among eleven pre-test participants, we further improved the questionnaire by changing ambiguous wordings, improving vague questions, and adjusting question layouts.

The final questionnaire contains the following sub-sections:

1) Introduction where we introduced the background and motivation of the Modus project, as well as the purpose of the questionnaire. Data protection guidelines were also provided, and the participants were asked to consent to the terms in order to further proceed with the survey.

2) Driver impact assessment which is one of the key sections of the questionnaire. We asked the experts to assess a list of drivers which may impact air transport supply, air transport demand, rail supply, and rail demand respectively, targeting the year of 2040. The drivers were structured along the STEEP-framework, which is already presented in the literature review. There are eight scales available to rate the driver effect, ranging from +3 (strong increase) to -3 (strong decrease), and with n/a to be selected in case of 'don't know' or 'cannot make an assessment'. We also encouraged the experts to provide comments and thoughts at the end of the question.

3) Assessment of future demand for air and rail travel by 2040 in Europe, where we asked the experts to assess the demand trend (growing, relatively stable, or declining) of air and rail travel for leisure and business purposes, respectively, as well as the trend of combined air-rail solutions.

4) Assessment of future supply for air and rail travel by 2040 in Europe, where we asked the experts to assess the supply trend (growing, relatively stable, or declining) of air travel, rail travel, and combined air-rail solutions.

5) Assessment of long-term impact of Covid-19 on future demand and supply of air and rail travel in Europe, where we asked the experts to estimate the time when air and rail transport will recover to reach the pre-Covid-19 level, the main drivers for reaching that level, and the aspects or areas which will be most affected in the coming ten years.

6) Demographic questions, where we asked the participants to indicate their industry, position, years of experience in transport or related sector, and how confident they are about the answers they provided.

3.4 Survey execution

The survey was distributed to experts via emails that have been collected on the contact lists on October 19th, 2020. A follow-up reminder email was sent on November 14th, 2020, which reminded the participants about the survey deadline. On November 24th, 2020, we officially closed the survey link. We received valuable feedback and comments concerning the survey design, experience of response, and the Modus project during the survey execution process.

3.5 Descriptive analysis of results

After more than one month, we collected 35 responses in total. Among those, 22 respondents completed the whole questionnaire, which results in a 63% survey completion rate. Meanwhile, as expected, the typical time spent on completing the survey was 20 minutes. The survey results are analysed based on the completed responses of each question. The details are described in the following sections.

3.5.1 Description of the research sample

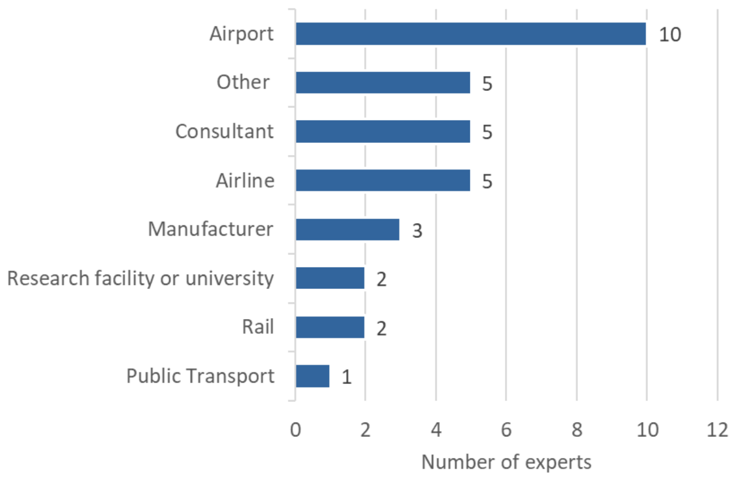


Figure 16: Industry/transport mode

Source: own depiction

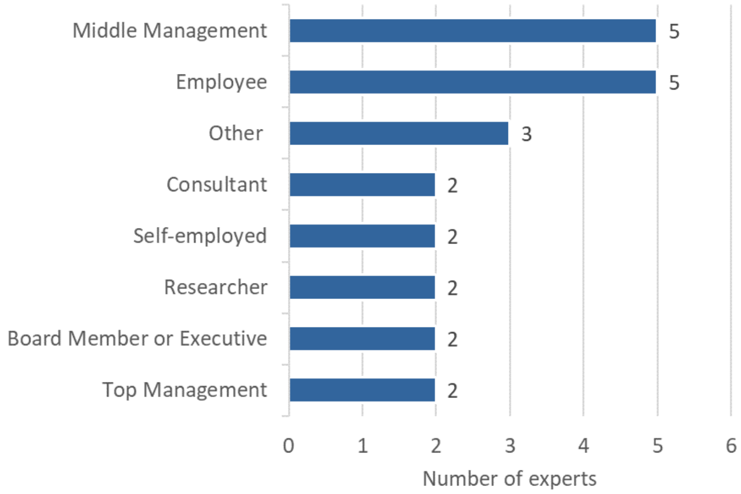


Figure 17: Job position

Source: own depiction

As shown in Figure 16 and Figure 17, experts who participated in the survey are diverse in terms of their working industries and job positions. More than half of the participants are from the aviation industry and include the airport and airline sector. Five experts work as transportation-related consultants. Another five experts selected *Other* categories, such as large trade association, travel and tourism, advocacy group, NGO, aeronautics industry and transport distribution, followed by three from the manufacturing industry. Experts from the rail and public transport sector only take a relatively small share[3]. It is also worth noting that six respondents selected more than one category of industry/transport mode.

Participants who chose *Employee* and *Middle management* formed the two main categories regarding job positions, followed by equally distributed groups including *Top management*, *Board member* or *Executive*, *Researcher*, *Self-employed* and *Consultant*, as shown in Figure 17. The remaining are *Volunteer*, *Research funding authority*, and *Management & expert*, as specified by the experts who selected *Other*.

[3] Due to the lower number of participants from the rail sector compared to air transport representatives, there might be some bias in the results. The findings from this expert survey are, however, only a small part of the project. Along with the literature review on multimodal supply and demand (Section 2), which covers air, rail and multimodal transport, this survey provides a complementary approach to identifying future drivers of demand and supply. Furthermore, in the course of the Modus project and in the next workshops as well as during potential interviews, more rail experts are intended to be involved.

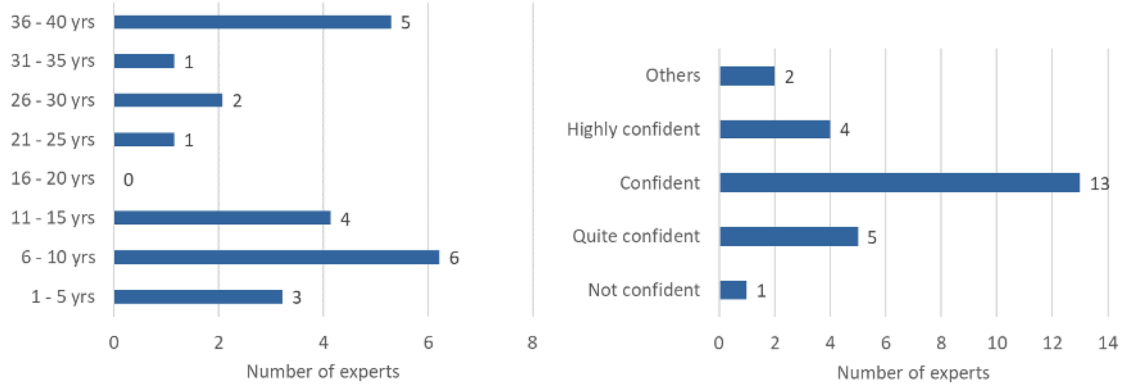


Figure 18: Years of experience and self-assessment of provided response

Source: own depiction

To assess experts' experience, we asked them to indicate how long they have worked in transport-related industries. The majority of the experts have been working in the field up to 15 years, followed by five having worked between 36 and 40 years in this sector. However, years of experience is not necessarily reflecting the expertise of making a judgement for the future. Therefore, we asked the experts to rate how confident they are about the answers they provided. As a result shown in Figure 18, the majority of the respondents stated between 'quite confident' to 'highly confident'. Only a few participants were not confident or had difficulties in understanding some of the questions.

3.5.2 Quantitative assessment of drivers

The survey analysis has been conducted in a descriptive manner so far. The approaches for analysing the drivers' impact and open text questions regarding the impact of Covid-19 are highlighted in the following sections.

3.5.2.1 Analysis of drivers' impact

To assess the drivers' impact on each of the four cases (air supply, air demand, rail supply, and rail demand) from social, technological, economic, environmental and political aspects, we broke down the analysis into three steps, as depicted in Figure 19. Firstly, we evaluated every driver of each aspect for all four cases by checking the basic statistics of the aggregated responses, including minimum, maximum, median, mean, standard deviation (SD), and coefficient of variation (CV) (SD/mean). Table 6 illustrates an example of the statistical assessment of how economic drivers may affect air transport supply. Meanwhile, we also analysed the distribution of driver assessment among experts. An example of assessing economic drivers for air transport supply is shown in Figure 20.

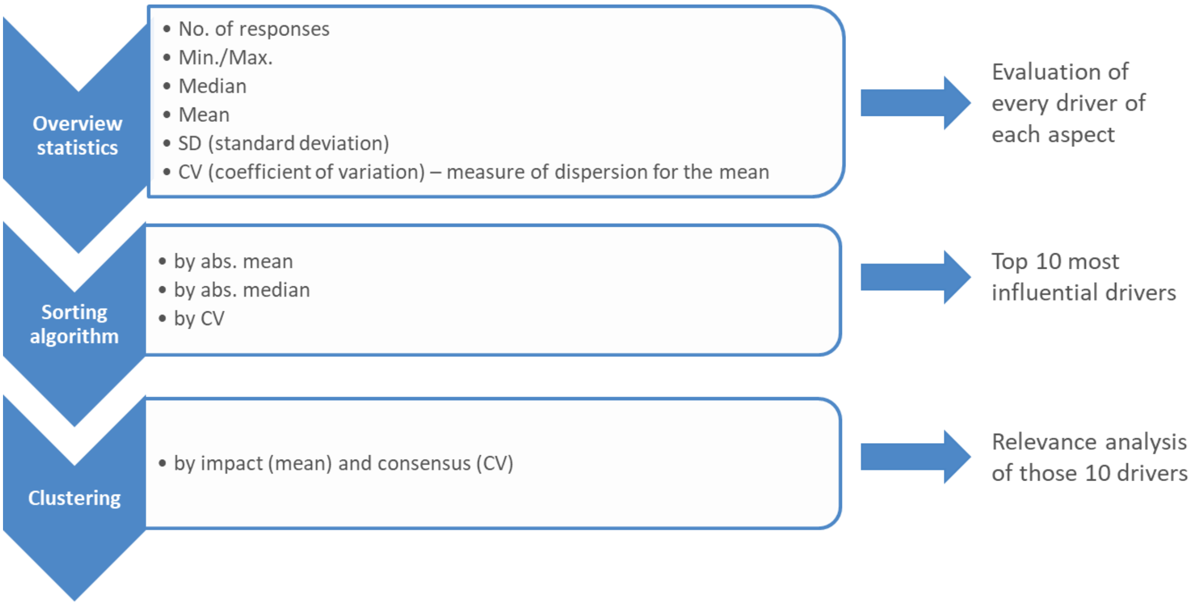


Figure 19: Work process of analysing drivers' impact

Source: own depiction

We then sorted out the top ten most influencing drivers by checking the absolute values of mean, absolute values of median, and CV based on the statistical information. For the final step, we further clustered the top ten drivers by checking the mean, which indicates the average ratings of impact and the CV, which depicts the consensus among all experts. According to a rule-of-thumb suggested by some grey literature, we selected 1.0 as a threshold for CV, meaning that all values below 1.0 show a relatively higher consensus among the experts. In contrast, the values above 1.0 indicate relatively lower consensus. As a result, the top 10 factors were grouped according to the judgements towards impact and the level of agreement among experts. We used colour coding to illustrate the relevance of the group drivers – green showing high relevance, yellow showing medium level, and red showing low relevance.

The work process mentioned above has been applied to evaluate the driver's impacts on all supply and demand cases of two transport modes and all STEEP aspects.

Table 6: Summary statistics of drivers' assessment

Driver	Sample	Min.	Max	Mean	Median	SD	CV
Economic/ GDP change	23	0	3	1.6	1	0.8	0.5
Change in disposable income	23	-1	3	1.3	1	1.2	0.9
Price of fossil energy (kerosene & diesel)	23	-2	3	0.2	-0.5	2.0	9.2
Price of non-fossil energy	23	-3	2	0.2	0	1.3	7.9
Evolving business models & market structures	23	-1	3	1.2	1	1.2	1.0
Intermodal integration; 'mobility as a service'	23	0	3	1.3	1	1.0	0.8

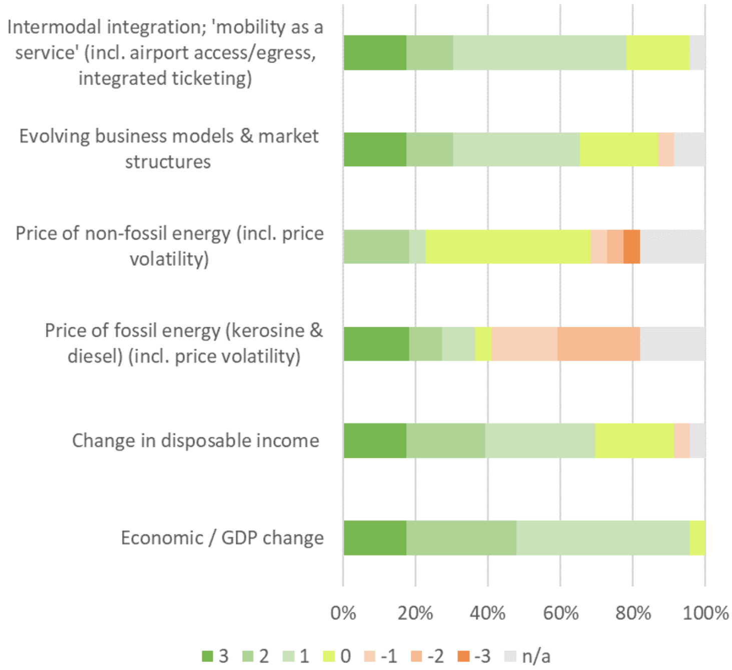


Figure 20: Distribution of assessment results among experts

Source: own depiction

3.5.2.2 Approaches for open-text analysis

To assess the long-term impact of Covid-19 on future supply and demand of air and rail travel in Europe, we asked the experts to provide comments on the main drivers for reaching pre-Covid-19 level, and the aspects or areas which will be most affected in the coming ten years. We implemented text mining to figure out the key drivers mentioned most frequently. However, due to the strong diversity of the comments regarding the aspects or areas that will be most affected, no meaningful keywords have been revealed through text mining. Most probably, the sample size is also too small for conducting advanced text mining. Therefore, we clustered similar responses and highlighted the main categories which can be found in the following section.

3.6 Key findings of expert survey

3.6.1 Top drivers

In general, most of the drivers have a positive impact (average mean > 0). There are also a few exceptions with drivers having decreasing impacts, for instance, *Health concerns* and *Communication technology* may have decreasing effects on supply and demand of both air and rail travel, while *Climate change* and *Regulatory change concerning environment* may have decreasing effects on only air travel supply and demand. However, experts' judgement did not reach a high consensus regarding those few drivers with negative impacts, and therefore, we excluded them as part of the key results. In the following part, we highlight the top ten drivers which have been sorted out according to their impacts and level of agreement among experts.

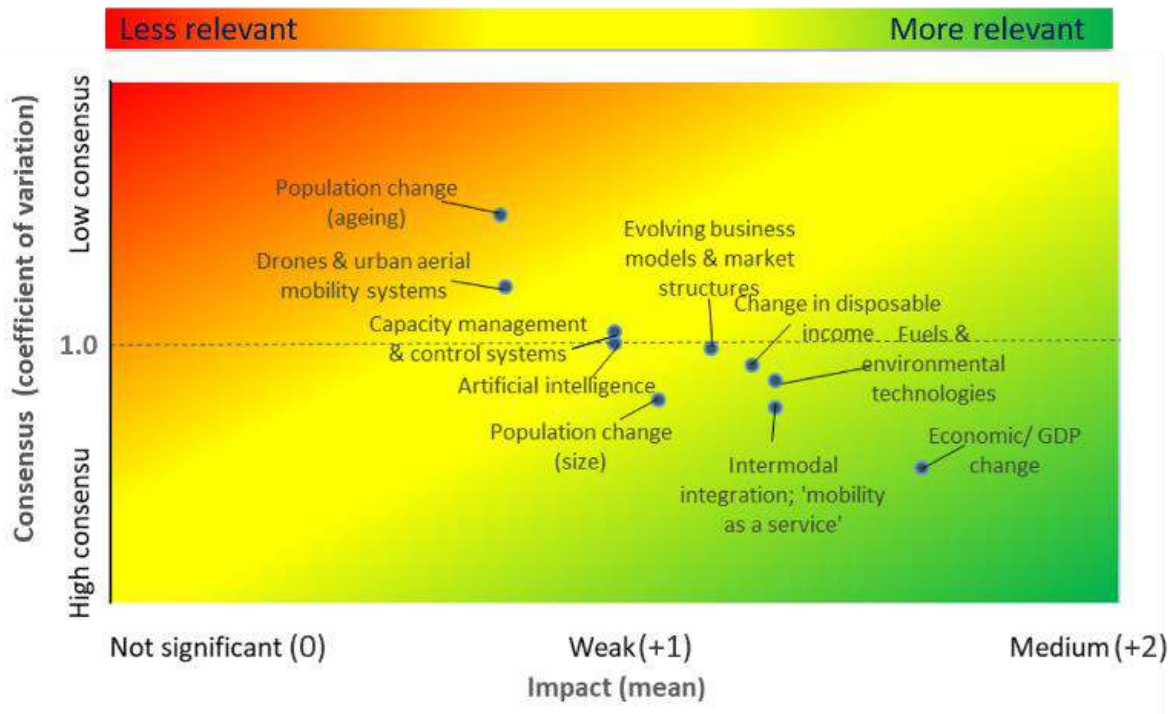


Figure 21: Top drivers for air travel supply

Source: own depiction

In terms of air travel supply (Figure 21), as we expected, experts reached a high level of agreement that the drivers *Growing economy and GDP* and *Fuels and environmental technologies* (for instance the usage of alternative fuels and more advanced vehicle design, etc.) will have a relatively more substantial impact. In addition, as one of the main goals of the Modus project, the driving impact of *Intermodal integration* has also been highlighted. However, some drivers seemed to be less relevant, such as *Population change due to ageing* and *Drones & urban aerial mobility system*. For the latter, we assumed that it could be due to the ongoing Covid-19 pandemic, which slows down the evolving progress of advanced air mobility.

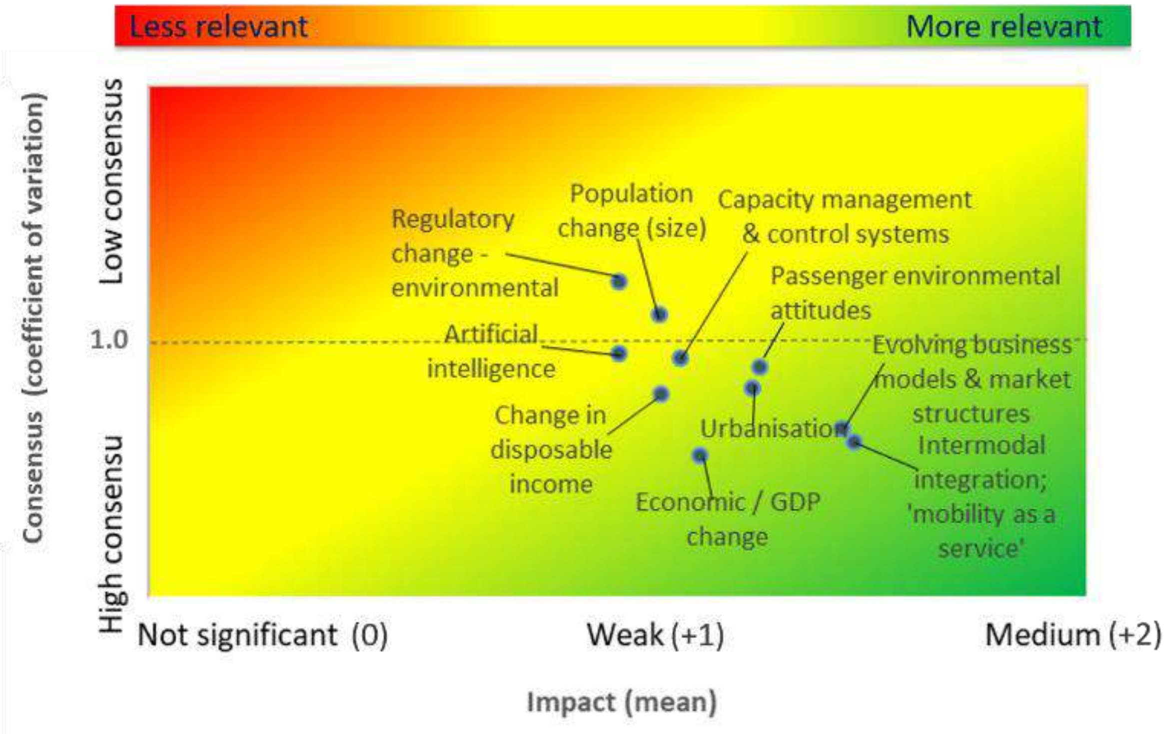


Figure 22: Top drivers for air travel demand

Source: own depiction

Regarding air travel demand (Figure 22), besides *Economic/GDP change* and *Intermodal integration*, *Change in disposable income* meaning the increasing financial resources and *Population change in size* may also foster the air travel demand. These strong assessment results are not too surprising and confirm the drivers already identified in the literature review. Whereas located in the red zone, the roles of *Population change due to ageing* and *New propulsion technology* (such as hypersonic air, hyperloop, etc.) are still debatable.

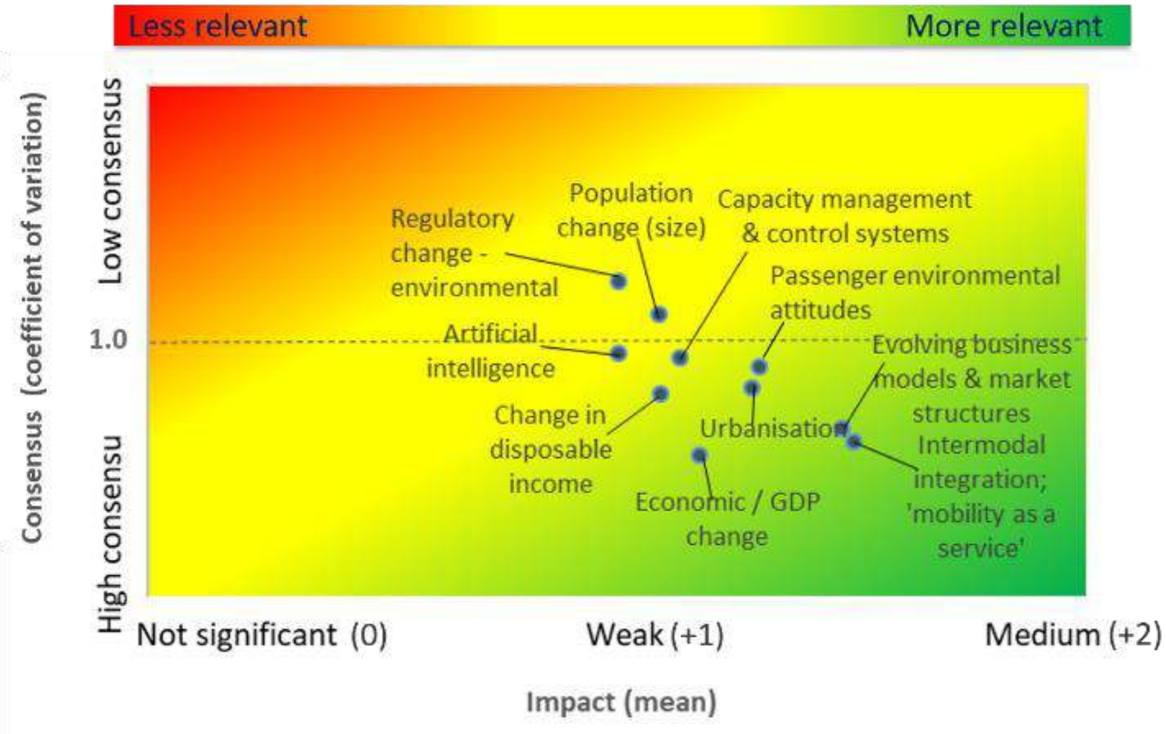


Figure 23: Top drivers for rail travel supply

Source: own depiction

In terms of rail travel, influencing drivers are different from those for air travel. Moreover, it seems that experts tend to have a higher level of agreement when assessing the drivers for rail travel. For rail travel supply, as shown in Figure 23, compared to the impact of *Economic and GDP change*, *Intermodal integration* as well as the corresponding *Evolving business models and market structures* are expected to be more relevant. Meanwhile, the increasing *Passenger environmental attitudes* and *Urbanization* may also increase the needs for more rail supply.

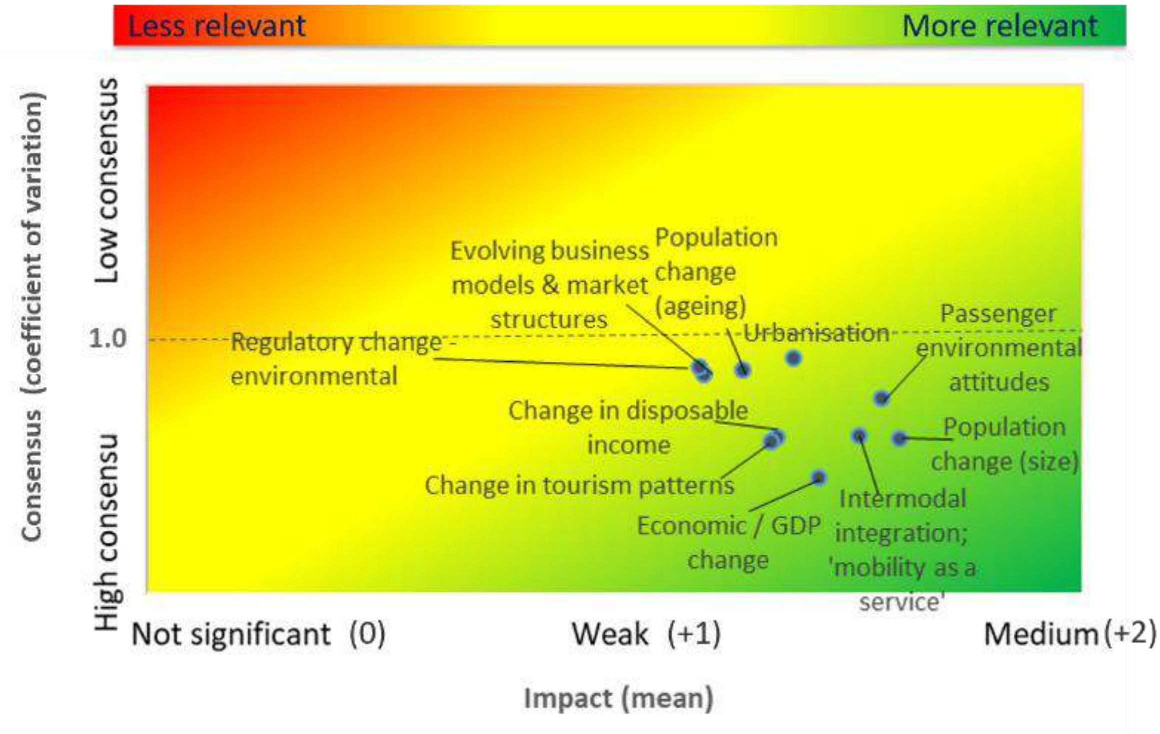


Figure 24: Top drivers for rail travel demand

Source: own depiction

It can been seen in Figure 24 that experts reached a relatively high consensus regarding rail travel demand drivers, since almost all the drivers fall into the green zone. Other than the previously mentioned factors which will foster rail travel supply, the *Environment-related regulation* (e.g. fuel duties; short-haul flight restrictions; European Green Deal) and *Change in tourism patterns* are also considered to be relevant to boosting rail demand.

3.6.2 Statistical testing

To further understand the difference between the revealed top drivers, we conducted Wilcoxon signed-rank test, which works with ranked/ ordinal data and is used to compare two related samples to assess whether their population mean ranks differ (Wilcoxon, 1945). The following four matrices of p-values illustrate the statistical difference of every paired top drivers for air travel demand, air travel supply, rail travel demand, and rail travel supply. The top drivers are colour-coded, corresponding to the clusters defined in the previous section. All the significant paired differences ($p \leq 0.05$) are highlighted in blue and with an asterisk.

Table 7: Statistical testing results for top drivers of air travel demand

	Economic / GDP change	Change in disposable income	Population change (size)	Intermodal integration	Fuels & environment. technologies	Immigration	Urbanisation	Evolving business models & market structures	Population change (ageing)	New propulsion technologies
Economic / GDP change	NA	0.627	0.175	**0.043***	0.226	**0.047***	**0.006***	**0.002***	**0.011***	**0.020***
Change in disposable income	NA	NA	0.360	0.243	0.368	0.108	0.097	**0.030***	0.053	0.067
Population change (size)	NA	NA	NA	0.608	0.620	0.381	0.063	**0.025***	**0.008***	**0.040***
Intermodal integration	NA	NA	NA	NA	1.000	0.643	0.115	0.063	0.131	0.101
Fuels & environmental technologies	NA	NA	NA	NA	NA	0.690	0.291	0.104	0.214	**0.036***
Immigration	NA	NA	NA	NA	NA	NA	0.718	0.560	0.681	0.436
Urbanisation	NA	NA	NA	NA	NA	NA	NA	0.407	0.626	0.891
Evolving business models & market structures	NA	NA	NA	NA	NA	NA	NA	NA	0.906	0.884
Population change (ageing)	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.512
New propulsion technologies	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 8: Statistical testing results for top drivers of air travel supply

	Economic / GDP change	Intermodal integration	Fuels & environment. technologies	Change in disposable income	Evolving business models & market structures	Population change (size)	Artificial intelligence	Capacity management & control systems	Drones & urban aerial mobility systems	Population change (ageing)
Economic / GDP change	NA	0.149	0.238	0.081	0.097	**0.016***	**0.027***	**0.020***	**0.007***	**0.005***
Intermodal integration	NA	NA	1.000	0.949	0.482	0.212	0.239	0.210	**0.018***	**0.037***
Fuels & environmental technologies	NA	NA	NA	0.881	0.507	0.432	0.250	0.174	**0.034***	0.074
Change in disposable income	NA	NA	NA	NA	0.831	0.294	0.325	0.466	0.205	0.094
Evolving business models & market structures	NA	NA	NA	NA	NA	0.774	0.608	0.437	0.115	0.165
Population change (size)	NA	NA	NA	NA	NA	NA	0.684	0.685	0.162	0.076
Artificial intelligence	NA	NA	NA	NA	NA	NA	NA	1.000	0.340	0.439
Capacity management & control systems	NA	NA	NA	NA	NA	NA	NA	NA	0.340	0.388
Drones & urban aerial mobility systems	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
Population change (ageing)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

In terms of air travel demand, eleven out of 45 pairs of top drivers (indicating a rate of 24.4%) were found to be significantly different. Other than the pair of *Economic/GDP change* and *Intermodal* *integration*, we revealed the significant difference between drivers in different clusters. Similarly, eight out of 45 pairs (indicating a rate of 17.8%) showed significant differences. Except for the two green factors, *Population change (size)* and *Economic/GDP change*, significant differences were found across clusters.

Table 9: Statistical testing results for top drivers of rail travel demand

	Population change (size)	Passenger environmental attitudes	Intermodal integration	Economic / GDP change	Urbanisation	Change in disposable income	Change in tourism patterns	Population change (ageing)	Evolving business models & market	Regulatory change -
Population change (size)	NA	0.943	0.748	0.363	0.495	0.254	0.297	0.149	0.127	0.190
Passenger environmental attitudes	NA	NA	0.559	0.491	0.813	0.445	0.360	0.452	0.137	0.072
Intermodal integration	NA	NA	NA	0.747	0.894	0.395	0.532	0.273	0.063	0.097
Economic / GDP change	NA	NA	NA	NA	1.000	0.627	0.644	0.543	0.325	0.340
Urbanisation	NA	NA	NA	NA	NA	0.949	0.794	0.630	0.632	0.615
Change in disposable income	NA	NA	NA	NA	NA	NA	0.854	0.881	0.642	0.754
Change in tourism patterns	NA	NA	NA	NA	NA	NA	NA	0.748	0.627	0.388
Population change (ageing)	NA	NA	NA	NA	NA	NA	NA	NA	0.646	0.724
Evolving business models & market structures	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.840
Regulatory change - environmental	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 10: Statistical testing results for top drivers of rail travel supply

	Intermodal integration	Evolving business models & market structures	Passenger environment. attitudes	Urbanisation	Economic / GDP change	Capacity management & control systems	Change in disposable income	Population change (size)	Artificial intelligence	Regulatory change environment.
Intermodal integration	NA	0.745	0.685	0.388	0.115	0.138	0.108	0.221	**0.028***	0.086
Evolving business models & market structures	NA	NA	0.454	0.491	0.309	0.183	0.196	0.204	**0.037***	0.097
Passenger environmental attitudes	NA	NA	NA	1.000	0.490	0.891	0.314	0.402	0.397	0.350
Urbanisation	NA	NA	NA	NA	0.659	0.719	0.521	0.287	0.253	0.356
Economic / GDP change	NA	NA	NA	NA	NA	0.894	0.608	0.974	0.468	0.559
Capacity management & control systems	NA	NA	NA	NA	NA	NA	0.801	0.935	0.374	0.517
Change in disposable income	NA	NA	NA	NA	NA	NA	NA	0.710	0.723	1.000
Population change (size)	NA	NA	NA	NA	NA	NA	NA	NA	0.717	0.673
Artificial intelligence	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.724
Regulatory change - environmental	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Regarding the top drivers of rail travel, only two out of 45 pairs (indicating a rate of 4.4%) were revealed to be statistically different for rail travel supply. We considered that this might also be affected by the limited participation of rail experts.

As it is often the case in surveys using semi-quantitative survey approaches, only a minor part of the top drivers have been found different from a statistical point of view. These findings, however, only make up a small part of the project. Hence we consider this as sufficient for the deliverable here in Modus. Therefore, along with the literature review on multimodal supply and demand (Section 2), the expert survey results are considered to contribute to identifying future drivers of demand and supply.

3.6.3 Trend assessment of future supply and demand

When asking the experts to assess the trend of future demand and supply for air and rail travel by 2040, most experts believe that the combined air-rail solutions will grow. Most experts think that travelling for leisure purpose by rail will grow, but fewer people think that this will be the case for air travel. Meanwhile, only a few experts foresee a growing trend for business travel by air, while most think it will stay relatively stable or even decline. All of these can be seen in Figure 25.

In terms of the assessment of future supply (Figure 26), similarly, combined air-rail travel is believed to be the most promising solution with the majority of experts indicating a growing trend. Compared with the rail transport supply case, fewer experts anticipate a growing trend in air transport supply.

However, still more than half of the respondents believe that the air transport supply will grow by 2040.

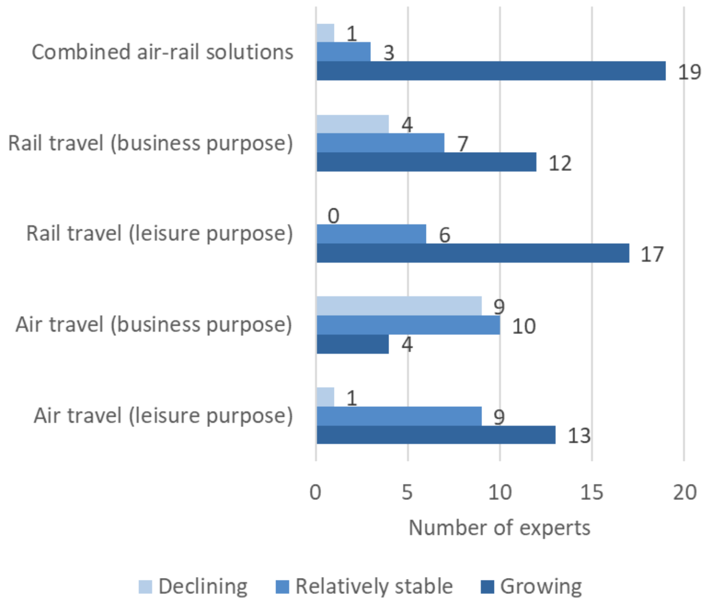


Figure 25: Trend assessment of future demand

Source: own depiction

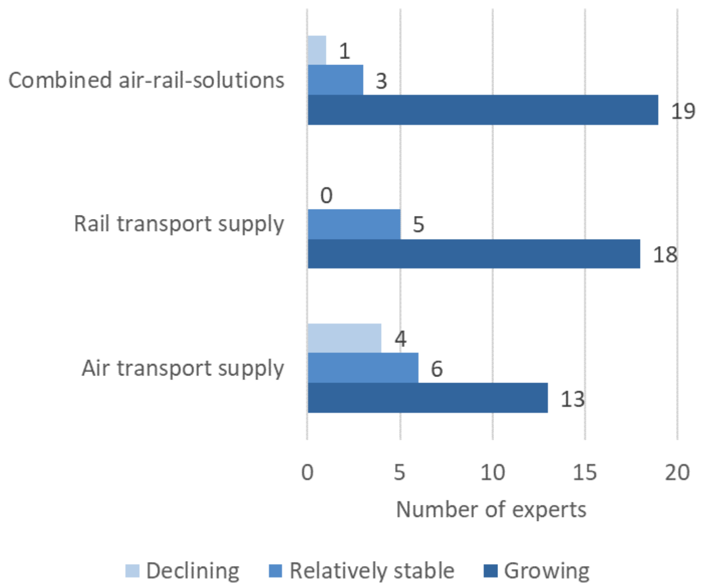


Figure 26: Trend assessment of future supply

Source: own depiction

3.6.4 Impact of Covid-19

To assess the long-term impact of Covid-19 on future air and rail travel, we asked the experts to indicate the time when they think that air and rail transport will recover and reach pre-Covid-19 levels[4]. As the following figure shows, most experts believe that rail transport will recover in the coming two years, which is expected to be faster than the time it may take for air transport to recover (in the coming three to five years). The forecast air travel recovery is comparable with Pearce [139], Chief Economist at IATA. He assumes an air travel recovery by 2024; however, still with many uncertainties in his prediction. Surveyed experts also indicate that air travel recovery might be reached firstly on a local or national level, supported by for instance travel bubbles (e.g. within a country or region). Other work supports this by elaborating a late recovery for long-haul flights, as hypothesised for business travel by Suau-Sanchez et al. [140]. In the rail sector, the UIC (the worldwide railway association) anticipates a progressive switch to the *New Normal*, not a breakthrough, triggered first at national and local levels by the vaccine diffusion and the related ease of travel restrictions. Due to geographical disparities, this is happening between now (in some regions) and 2025.

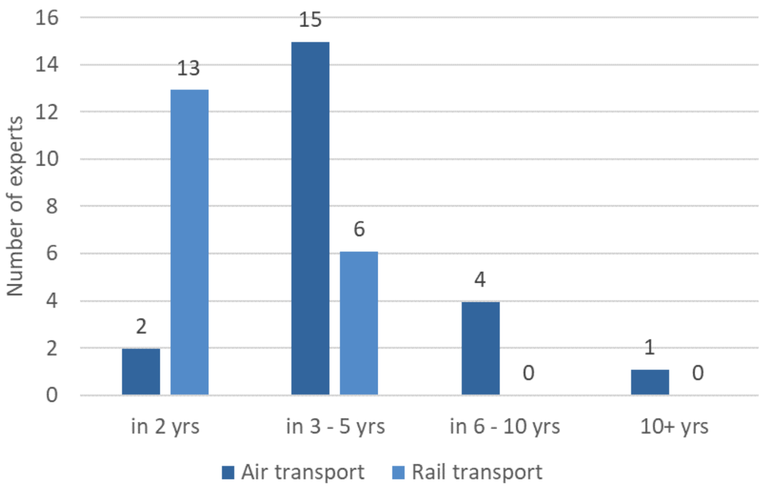


Figure 27: Estimation of time when air and rail travel will recover to pre-Covid-levels

Source: own depiction

When analysing the proposed drivers that may contribute to air and rail transport recovery, we found that vaccination has been mentioned most frequently, followed by Covid tests and passenger confidence. Other mentioned drivers that are environmental-goals-driven include adopting zero-emission aircraft and climate-neutral propulsion technologies and increasing the awareness to travel

[4] Currently, there are a lot of detailed studies and forecasts on the development of air and rail traffic after the Covid-19 pandemic. Since the time horizon of Modus is 2040+, the short to medium-term developments are only partly within the focus of this project. Therefore, the section on Covid-19 in the survey has been left open-text in order to collect a large variety of views in regard to how the transport sector might recover from the pandemic. The potential long-term impact of the pandemic in terms of reduced air traffic levels or a stronger push for environmental regulations facilitated by the pandemic, for example, will be highlighted in the Modus scenarios in deliverable D3.2.

more sustainably. Most of these drivers are already discussed in the literature review, however, the drivers 'vaccination', 'Covid tests', and 'passengers' confidence' are novel drivers not covered by literature review yet (see also Section 6).

Next, open text answers are converted into a causal loop diagram to show interconnectivities and identified key factors (these are the underlined factors in Figure 28). As depicted from the experts' answers, the demand for leisure and business travel is strongly driven by passengers' confidence to travel. Hence, confidence levels will play a key role to overcome the current Covid-19 related crisis. Other work supports this [141]. Air and rail transport providers are advised to focus on regaining passengers trust into all travel modes. Next to learnings from harmonized, hygienic procedures, long-term resilience within the transport system can also be reached by providing climate-neutral transport options. Other factors, such as changed business communications, can also have a negative long-term effect on travel demand. Advanced communication tools might replace a share of business travel long-term. This could be, for instance, the substitution of internal meetings with online meeting tools.

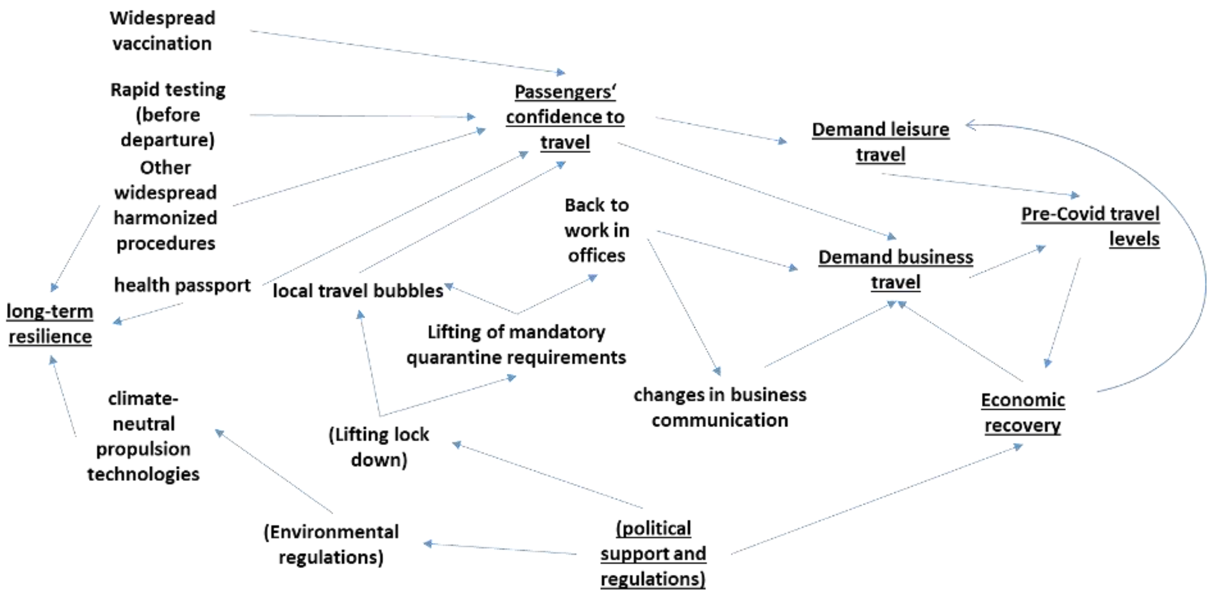


Figure 28: Drivers for recovery towards pre-Covid-19 travel levels (expert survey, air and rail travel)[5]

Source: own depiction

Due to the impact of Covid-19, experts believe that almost all aspects of air transport will be severely impacted in the coming ten years. Some main areas for air transport include flights across different distance segments (short- and long-haul), air travel for various purposes (business, leisure), airline business models and revenue, cabin crew and staff, airport transit time, on-board and border control regulations, and communication technology, etc. For rail transport, besides travel for different trip distances and purposes, other mentioned aspects include punctuality, seat capacity, high-speed rail, passenger protection, and travel retail. Interestingly, a potential shift of mode preference from air to

[5] Bracketed factors added by consortium

rail has been highlighted, possibly due to the increasing environmental awareness, which may bring a chance to foster the sustainable transition in the transport sector.

3.6.5 Expert survey synthesis

The expert survey has gathered the views of various experts from different transport sectors on the factors with the most influence on possible futures for European travellers. The survey provides complementary insight to the detailed literature review and the respective discussion of future drivers for supply and demand.

In order to evaluate the various drivers' potential impact, descriptive statistics analysis and clustering was conducted. As a result, the driver *Intermodal Integration* was recognized as a crucial driver for the development of supply of and demand for both air and rail travels. Moreover, experts highlighted *Growing Economy and GDP* as a main driver for the future supply of and demand for air travel, whereas the growing *Passenger Environmental Attitudes and Regulation* was identified as a major driver that might boost the supply of and demand for rail travel. In addition, *Fuels and Environmental Technologies*, such as the usage of alternative fuels and more advanced vehicle design, was seen as a noteworthy air supply driver.

In general, a growing trend of the combined air-rail solution was highlighted. Experts predict a growing trend for leisure travel by rail; however, the consulted experts assume that both leisure and business travel by air may stay relatively stable or even decline. The experts foresee a faster recovery of rail transport in the following years. The open-text approach reveals those factors that have a strong influence on the recovery of air and rail travel. By using text clustering, the following areas have been highlighted most: “vaccination", "COVID tests", and "passengers' confidence".

The survey might exhibit some bias since less representatives from the rail sector participated than from the air transport sector. The findings from this expert survey are, however, only a small part of the project. Along with the literature review on multimodal supply and demand (Section 2), which covers air, rail and multimodal transport, this survey provides a complementary approach to identifying future drivers of demand and supply. Furthermore, in the course of the Modus project and in the next workshops as well as during potential interviews, more rail experts are intended to be involved. Moreover, statistical testing results confirm that only a minor part of the top drivers had significant differences in both air and rail travels. This result might also be improved with more participants from different sectors involved. Considering the above limitations, we believe that conducting future workshops might help improve the results by gathering more inputs from experts from various domains.

4 Modus Multimodality Workshop

4.1 Introduction

The first Modus workshop (workshop 1) about "The Future of Multimodal Transport: Horizon 2040" took place online on 19th January 2021. Attendance to the workshop was very good (more than 80 people) and represented a reasonable cross section of air and rail expertise, with a mix of operators and researchers particularly involved in other multimodality projects. Registration amounted to more than 110 people and included 75% of transport operational actors, with approximately 2/3 of aviation (airports, airlines, ANSP, research centres, interest groups) and 1/3 of rail transport (stations, rail operators, interest groups); the other 25% included 2/5 of universities, 2/5 of transport consultants and 1/5 of representatives of ministries, regulators and SJU. Clean Sky, SYN+AIR, X-TEAM D2D projects also registered in the workshop.

This section presents an analysis and consolidation of the verbatim comments collected during the workshop, in particular the interactive brainstorming session with the participants. This was carried out virtually using a combination of remote meeting tools and the virtual whiteboard app, 'MURAL'. The aim was to confirm, or otherwise, and complete the identification of supply and demand drivers for future multimodal (air) transport performed via other means and reported in Sections 2 and 3. The participants addressed the following enabler topics for future multimodality at the horizon 2040:

- **What are infrastructure needs and feasibility?**
- **Which business models can support and enable multimodality?**
- **What do passengers of the future look like in terms of personalisation, travel services?**

This section describes first the brainstorming process and then provides a detailed analysis of the brainstorming outcomes. It concludes with a synthesis of the most prominent findings. The inputs relevant for the next steps in Modus are addressed in Section 6.

4.2 Workshop brainstorming process

Due to high attendance at the workshop, the session was organised within 6 sub-groups of attendees, which were distributed across the groups according to the 3 enablers topics listed above, aiming at an even distribution of representatives from the different transport sectors and research domains (2 groups per topic).

Within each group, each participant was asked to contribute their ideas and thoughts within the scope of an issue analysis process. Each participant wrote various bullet points on electronic 'post-its' in MURAL, which were described and discussed within the group, under the guidance of a moderator and with the support of a co-moderator, both from the Modus team. Following this, the ideas are grouped into several clusters, which are given a title in order to indicate the high-level multimodal topic each cluster represented.

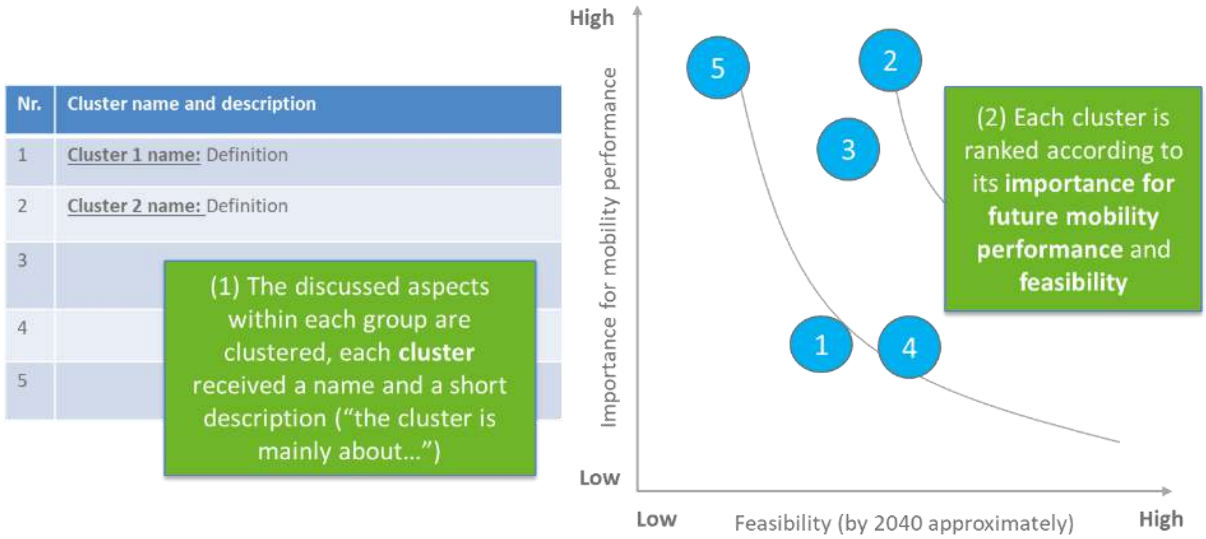


Figure 29: Cluster analysis and assessment within each group

Source: own depiction

In the next step, the clusters were ranked according to their perceived high-level importance for future mobility performance as well as their feasibility in terms of being implemented by 2040 (see Figure 29). The clusters produced by the groups can be found in Appendix C of the deliverable.

The outcome of the different group discussions were very rich and show the vast area of improvements that is needed for multimodal mobility in Europe. There are multiple challenges and opportunities when moving towards a multimodal European transport system. Early findings about some key enablers for a multimodal transport include:

- Data as key enabler for improvement (sharing across providers, security and privacy, initiation of shared platforms, travel companions).
- Focus on regulations, which are an important foundation to introduce multimodal solutions.
- Passenger focus of utmost importance when considering infrastructure needs, business models, and door-to-door journeys.

A more detailed analysis per category of multimodality enablers is presented in the following in order to identify the main elements to include in the future multimodal drivers as well as in other work packages of the Modus project.

4.3 Detailed analysis of the workshop findings

The methodology for analysing the workshop findings, based on the merge of the verbatim comments and of the prioritisation made by the two groups that were allocated to each enabler topic, include the following steps:

- Per topic, merging the clusters allowed the regrouping into broad categories common to all topics, coded in different background colours:

- grey = strategic perspective about infrastructure, finance, companies, standardisation, regulation;
- green = environmental impacts;
- blue = operational perspective on collaboration across modes;
- yellow = passenger perspective regarding the planning and execution of the multimodal journey;

- Per topic, graphically superposing the priorities[6] attributed to clusters by the two groups working on the same enablers topic allowed identifying quick-wins, i.e. improvements assessed by the participants as both important for mobility performance and feasible by 2040 approximately.
  - Red boxes at the upper right corner of the graphs highlight these (see Figure 30, Figure 31, Figure 32)
  - In the upper left corner of each graph, another box identifies the important aspects assessed as less to hardly feasible by 2040 by the workshop participants.
- A few conclusions came from reconciling the enabler topics and the priority quick wins, as well as the less feasible but important aspects.
- Finally, from this analysis the report identifies inputs to consider in the following tasks and work packages of Modus (see Section 6).

4.3.1 Infrastructure needs and feasibility

4.3.1.1 Grouping infrastructure clusters into categories

The merging of the clusters produced by Group 1 and Group 2 is presented in Table 11.

Table 11: Categories of infrastructure needs

Category	Cluster number and name	Cluster definition
Infrastructure	1 - Infrastructure capacity	Infrastructures should avoid bottlenecks and make intermodality possible with better hubs and connections, connecting air and rail with the regional, national and international territory with dedicated policies and funds

[6] Note: from a methodological point of view, in particular due to the little time allowed for the whole exercise during the workshop and in particular due to the graphical representation of priorities in terms of importance vs. feasibility, the assigned priorities may represent a subjective view and therefore have to be considered as initial starting point for further, more detailed discussion and assessment. As a consequence, the results presented here are indicating trends rather than any type of numerical evidence.

Category	Cluster number and name	Cluster definition
		that enable it, taking in account new technologies and sustainable issues.
	2 - Connectivity	UAM-rail-train at multimodal hubs; infrastructure funding; parking; public links airports to city-centre
	3 - Airport design	Access to several modes at airports, design for more passengers
Less air trips	4 - Environment	'Unnecessary' trips and noise at the airport
Multimodal cooperation & D2D IT system	5 - IT System D2D / passenger data sharing / trust between modes / collaboration	The D2D development requests data availability and data sharing, collaboration between different transport modes and adapted policies are necessary.
	6 - Collaborative processing across modes	Coordination of actors across modes for a D2D passengers experience (air-rail-urban transport)
	7 - Information/ data sharing	Coordination between modes
	8 - Complementarity between air & rail for security	Complementary security policy between air and rail is important to reduce administrative burden.
Passenger planning	9 - Passenger planning (ICT needs)	Multimodal info to passengers in planning & execution
	10 - Economics	Multimodal trip pack creation & insurance
	11 - Ticketing interoperability	Ticketing interoperability between air and rail is essential to improve D2D passenger experience and it has to be flexible enough in case of disruption.
Passenger experience	12 - Passenger journey experience	Integrated tickets; Fluid & consistent travel info and facilities across modes on multimodal trip & countries (e.g. Covid); passenger diversity (disabled, languages, infrequent travellers)
	13 - Information to improve passenger experience	Real time, user-friendly, accessible and accurate information would improve passenger experience before and during the trip. Transfer time, development of intermodal hubs between modes of transport and information in case of disruptions are some key elements on the subject.
	14 - Flexibility - resilience	Disruption for passengers and flexibility to recover – buffer time
	15 - Luggage handling infrastructure	Passengers expectations on luggage multimodal transport
	16 - Luggage	Operational and security alignment on luggage handling across air and rail systems is important to enable seamless, intermodal and traceable solutions.

Main findings:

- In terms of multimodal infrastructure, airports need to be designed as multimodal hub platforms (air, rail, UAM, roads and parking) with connections to international traffic as well as to cities, potentially allowing more space in the future for passengers coming to the airport by rail.
- The environmental pressure to reduce air traffic was noted explicitly as a social driver for change. Participants mentioned sustainability in several other clusters as a requirement for multimodality improvement.
- Coordination and collaboration between actors across modes is reported to be essential. This goes with data sharing about/ for passengers supported by ICT tools. Alignment of signalisation and of security procedures across modes and across countries is required.
- For the passenger, ICT will support the multimodal journey planning as well as the passenger experience. Integrated journey packages (including insurance) and consistent travel information are prominent. Luggage handling and security are very important to be addressed for multimodal passengers. Finally, passengers need support and flexibility in case of disruption.

4.3.1.2 Infrastructure needs assessment

Five multimodality infrastructure improvements appear as quick-wins (boxed in bold red in Figure 30 below) as well as three others, very close but assessed as less feasible:

2 Connectivity
8 Complementarity between air & rail for security

6 Collaborative processing across modes
7 Information/ data sharing
5 IT System D2D / passenger data sharing / ~~trust between modes~~ / ~~collaboration~~
13 Information to improve passenger experience
15 Luggage handling infrastructure

16 Luggage

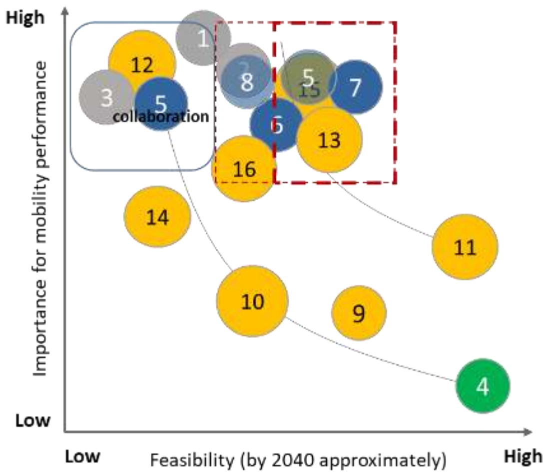


Figure 30: Most important and feasible infrastructure requirements

Source: own depiction

In the bold red box, most of the operational collaboration improvements (from the *Multimodal cooperation & D2D IT system* category) were deemed to be both important and feasible by 2040. Similar assessment for (from the *Passenger* category) the *Luggage handling infrastructure* (Cluster 15), the provision of information to passengers in real time, user-friendly, accessible and accurate before and during the trip including transfer time, and information in case of disruptions.

In the light red box, improving the *Connectivity* (Cluster 2) and the *Complementarity between air& rail for security* (Cluster 8) are also assessed as important but less feasible by 2040.

Important to note in the blue box that *Collaboration*, although important, was assessed far less achievable than the availability of tools to support data sharing across modes. *Infrastructure capacity* and *Airport design* are important to foster multimodal transport but were considered hardly feasible. Similar views existed regarding *Trust between modes*, essential to improve passengers experience but difficult to achieve.

4.3.2 Business models to support and enable multimodality

4.3.2.1 Grouping business model clusters into categories

The merging of the clusters produced by Group 3 and Group 4 is presented in Table 12.

Table 12: Categories of business model evolution

Category	Cluster number and name	Cluster definition
Business models	1 - Financing infrastructure sustainability	The need of financing/investing on infrastructure (consideration of public/private cooperation)
	2 - Air-rail cooperation	Sharing/agreeing on market short-haul/etc.
	3 - Air-rail competition	Keeping competition on links
	4 - ICT on D2D	The role of ICT companies on access/egress full D2D trip.
Regulation	5 - Regulatory framework	The role of standardisation, regulation environment, ticketing
	6 - Regulation to ensure level playing field for service providers	Preventing market dominance or uncompetitive pricing from limited providers, not limiting market access for others
Multimodal cooperation	7 - Provision of a seamless, single booking tool	Having single tools / booking services whereby a full D2D journey may be booked
	8 - Requirement for integrated, private data	All service providers are able to sell capacity into integrated booking systems, but retain their own supply privacy
	9 - Integrated dynamic capacity	Ensuring that capacity across modes is integrated and responsive to real-time demand and changes
	10 - Data sharing and management	Data sharing between stakeholders (rail/air)
Passenger experience	11 - Passenger flow at airport	The role of the airport as a connection hub managing flow of passengers.
	12 - Improved stakeholder stress & inclusivity	Improving the journey experience for the passenger, delivering better confidence for all stakeholder types
	13 - Intermodal transfer accessibility and efficiency	Improving connection times and reliability at cross-modal interfaces

Category	Cluster number and name	Cluster definition
	14 - Better passenger disruption services & tools	E.g. enabling passengers to re-book and re-plan during disruption (further developing existing tools)

Main findings:

- The business models for multimodal transport will be facilitated via the development of inter-company agreements on specific markets, and supported/encouraged by regulation. Standardisation will be needed for multimodal services.
- At the operational level, integrated booking tools and data sharing preserving privacy will allow selling multimodal capacity responsive to real-time demand and changes.
- For the passenger, airports are required to be designed for a multimodal passenger flow and to improve connection times, and flexibility to re-book during disruption are prominent.

4.3.2.2 Business model evolution assessment

Five multimodality business model improvements appear as quick-wins (boxed in bold red in Figure 31 below) as well as two very close but less feasible ones, in the light red box:

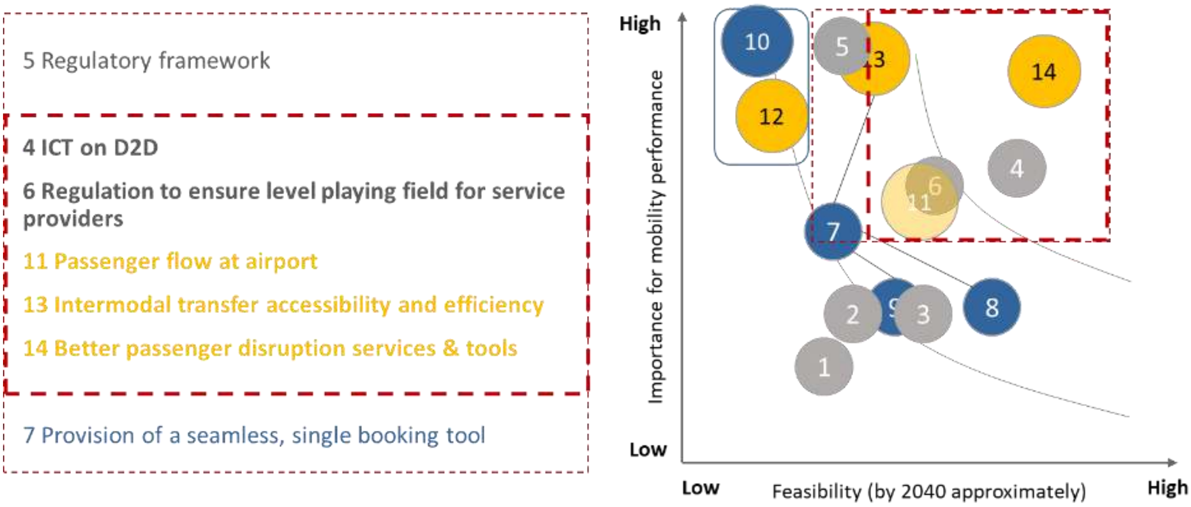


Figure 31: Most important and feasible business model evolution

Source: own depiction

Almost all of the improvements in the category *Passenger experience* were considered as quick-wins, both important and feasible, as well as the elaboration of appropriate regulations to support multimodality businesses. The provision of ICT tools to facilitate the entire journey from door-to-door and the availability of unified booking tools to support future multimodal business models are both considered important whereas the latter seems less achievable.

On the other hand, participants assessed the business models in terms of *Improved stakeholder stress & inclusivity* (Cluster 12) and for *Data sharing across modes* (Cluster 10) with a low feasibility by 2040 although very important to consider in future business models.

4.3.3 Needs of passengers of the future

4.3.3.1 Grouping passenger needs clusters into categories

The merging of the clusters produced by Group 5 and Group 6 is presented in Table 13.

Table 13: Categories of needs for passengers of the future

Category	Cluster number and name	Cluster definition
Infrastructure	1 - Regulations	The need for multimodal regulations
	2 - Security	Streamlining security requirement between modes
	3 - Network integration	The integration of networks and timetables between modes
Ticket price	12 - Green travel	Transparency and information, eco-friendly modes along D2D
	13 - Price and cost	The process for establishing prices based on costs of travel of the different transport modes
Passenger planning	4 - Journey planning	How to improve the D2D options/information for the multimodal travel for passengers
	5 - Booking and ticketing	Offering one ticket for the multimodal trip
	6 - Travel planning	Planning & manage disruptions from the demand perspective
	7 - Ticketing innovations	Single ticketing; MaaS tickets, one stop shop
Passenger experience	8 - Seamless and multimodal connections	Reducing D2D travel time, seamless travel, travel costs, multimodal offers
	9 - Personalisation of travel	Inclusion, personal preferences, peace of mind, safety
	10 - Accessibility and comfort	Providing better access and comfort
	11 - Information in disruption	The information for passengers on disruptions

Main findings:

- Infrastructure improvements for the passenger include new regulations, streamlined security requirements and integration of networks across modes.
- The passenger of the future will require multimodal integrated planning, booking and ticketing facilities. Ticket prices reflecting environmental impact will be expected. Multimodal

experience should be improved through seamless connection as well as personalised services for diverse travellers and better information in case of disruption.

4.3.3.2 Passenger needs assessment

Three improvements appear as quick-wins for the passengers of the future (boxed in bold red in Figure 32 below) as well as four very close ones although less feasible (light red box):

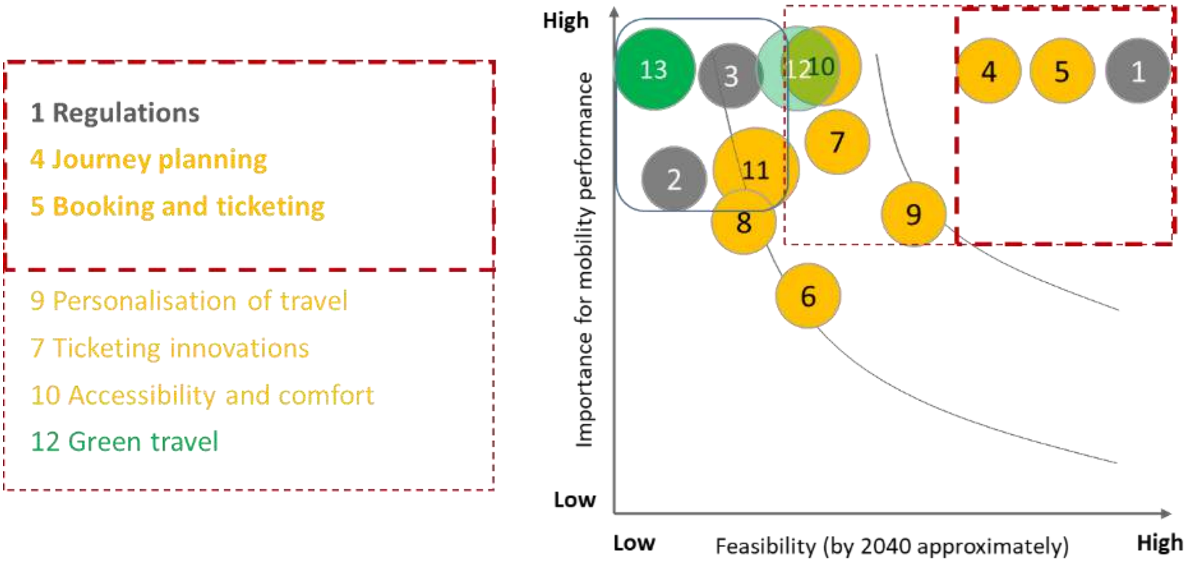


Figure 32: Most important and feasible improvements for passengers

Source: own depiction

For the passenger, appropriate *Regulations* for multimodality are important and assessed as highly achievable by 2040. Quick-wins include improvements to planning, booking, ticketing; although less feasible, the workshop participants also expected personalisation, accessibility and comfort, and green travel to be achievable by 2040.

Finally, participants judged very important but hardly feasible in the timeframe the availability of information in disruption, of streamlined security requirement and multimodal network integration aspects that require streamlining processes across modes, as well as pricing transparency to reflect the true cost of transport.

4.4 Synthesis of the workshop analysis

The assessment of participants within the 1st Modus workshop on the future of multimodality in Europe by 2040 highlighted the most promising aspects to improve, as shown in Table 14 below.

Table 14: Synthesis of improvement potential across multimodal enablers by 2040

	Infrastructure	Business models	Passengers
Strategic	Connectivity	**Regulation to ensure level playing field for service providers** **ICT on D2D** Regulatory framework	**Regulations**
Environment			Green travel
Operational collaboration across modes	**Information/ data sharing** **IT System D2D / passenger data sharing / trust between modes / collaboration** **Collaborative processing across modes** Complementarity between air & rail for security	Provision of a seamless, single booking tool	
Passenger perspective	**Information to improve passenger experience** **Luggage handling infrastructure** Luggage	**Intermodal transfer accessibility and efficiency** **Better passenger disruption services & tools** **Passenger flow at airport**	**Journey planning** **Booking and ticketing** **Personalisation of travel** Ticketing innovations Accessibility and comfort

The elements in bold were assessed both as most feasible and most important for the performance of the future European transport system. The remaining elements were considered as slightly less important but still feasible by 2040. According to the participants, regulations are essential to foster multimodal transport provision. Future passengers will consider their environmental impact but this was highlighted during the workshop to be not as prominent. Data sharing and tools, including for security reasons are essential to support multimodality, but operational collaboration and trust across modes will be more difficult to achieve. Finally, a lot can be done for the passengers in terms of multimodal information at booking and journey times, and in support during transfers and disruptions.

Also interesting to note in Table 15 below are those items that the workshop participants identified as most important while less feasible. These could become gaps and barriers to the improvement of multimodal transport by 2040. According to the participants, infrastructure capacity and airport design are important to foster multimodal transport provision but hardly improvable. Collaboration, trust across modes are essential but difficult to achieve, whereas these are important to improve passengers experience in particular regarding security and during disruptions. Participants recognised improving stress and inclusivity for all categories of passengers as important whilst more difficult to achieve. Finally, ticket prices reflecting the true costs of transport was seen unlikely by 2040.

Table 15: Important but less feasible improvements to multimodality by 2040

	Infrastructure	Business models	Passengers
Strategic	Infrastructure capacity Airport design		Network integration Security
Environment			Price and cost
Operational collaboration across modes	Trust between modes / collaboration	Data sharing and management	
Passenger perspective	Passenger journey experience	Improved stakeholder stress & inclusivity	Information in disruption

4.5 Potential enablers and barriers addressed during workshop

Table 16 below outlines those improvements which have been discussed during the Modus workshop as very useful to be introduced by 2040 and thus fostering multimodal transport. These are factors to consider in the next steps of Modus, the bold ones being considered most likely to happen by 2040, as highlighted by the experts. The table shows (A) Potential **(strong) enablers** regarding the improvement of the multimodal European transport system, discussed as being both very important and feasible (in bold), and slightly less important and feasible to realize by 2040, and (B) Potential **barriers** regarding the improvement of the multimodal European transport system, discussed as being important in the workshop but rather difficult to realize by 2040, which could constitute barriers to future multimodality could constitute barriers to future multimodality. Further, the table also outlines the potential valuable input for further work in Modus.

Table 16: Potential enablers and barriers for a future multimodal transport system

High-level category	Enabler / Barrier	Input for further work in Modus			
		Scenarios (D3.2) Use cases (D5.1)	Modal choice (D3.2)	Passenger mobility modelling (D4.2)	Gaps and barriers (D5.2)
Infrastructure improvements by 2040	Potential enablers	**Information/ data sharing** **IT System D2D / passenger data sharing / Collaborative processing across modes**			**Trust between modes/collaboration** Complementarity between air & rail for security Connectivity
	Potential barriers			Infrastructure capacity Airport design	Network integration Security
Business models evolution by 2040	Potential enablers	**Regulation to ensure level playing field for service providers** **Intermodal transfer accessibility and efficiency**	**Better passenger disruption services & tools** **ICT on D2D** Provision of a seamless, single booking tool	**Pax flow at airport**	Regulatory framework

High-level category	Enabler / Barrier	Input for further work in Modus			
		Scenarios (D3.2) Use cases (D5.1)	Modal choice (D3.2)	Passenger mobility modelling (D4.2)	Gaps and barriers (D5.2)
	Potential barriers		Data sharing and management		Trust between modes / collaboration
Improvement for Passengers 2040	Potential enablers	**Regulations** **Booking and ticketing (tools)**	**Information to improve passenger experience** **Journey planning** **Personalisation of travel** Green travel	Luggage **Luggage handling infrastructure**	Ticketing innovations Accessibility and comfort
	Potential barriers		Price and cost Passenger journey experience Information in disruption		(Improved stakeholder stress & inclusivity)

5 Modelling Modal Choice

5.1 Literature review modal choice

This section focuses on the different models used in empirical literature related to transport market to understand and predict transport demand, both in terms of quantities demanded and in terms of users' modal choices, when facing changes in their demand drivers (see section 2 for a description of the demand drivers).

Two main categories of econometric models can be considered for the analysis of demand. The first category relates to discrete choice models and the second to continuous variable models. The difference between these two types of model lies in their objectives. Discrete choice models are used to estimate a choice from a set of alternatives that are mutually exclusive, i.e. they cannot occur at the same time, and collectively exhaustive, which means that at least one choice is made. The discrete choice model is therefore a probabilistic model which estimates the probability of each alternative. For example, these models can predict the probability of choosing a transport mode depending on the passenger’s individual characteristics. This type of model allows the analysis of transport providers’ market shares and their dependence on the passenger’s characteristics.

Continuous models are used to analyse a quantity demanded, for example a number of trips or volume of passengers, depending on demand drivers. These models allow assessing demand elasticities, which measure the variation of quantity demanded following a variation of one demand driver. For example, this type of model can predict changes in transport demand if the price of transport is modified. These indicators are determinant in transport service providers’ strategies of supply.

This literature review is organized in two parts. The first part deals with discrete choice models, while in the second part we describe continuous choice models. Each section discusses the objectives as well as the advantages and disadvantages of each type of model.

5.1.1 Discrete choice models

Two types of discrete choice models are traditionally used in the empirical literature related to passenger transport choices: the multinomial logit model and the mixt logit model. We present here these two models illustrating their use in recent studies.

Zhao et Yan [142] use a multinomial logit model to analyse the emergence of new mobility services such as carpooling, bike sharing, car sharing and micro-transit using data on the stated-preference of staff and students at the University of Michigan. They predict the market-share of these new services and depict the induced changes in travel behaviour. In their paper, the multinomial logit is described as a model "frequently questioned for its assumption of independence of irrelevant alternatives and its inability to take into account variations in taste between different individuals". Indeed, the disadvantage of the MNL is that individuals are statistically identical which results in identical choices without taking into account individual preferences. Furthermore, the assumption of independence of irrelevant alternatives tends to make the model unstable when new alternatives are introduced [143]. Nevertheless, the advantages of the multinomial logit are its ability to handle more than two alternatives at the same time and its easiness of interpretation of the estimated coefficients.

The mixed logit model enables to overcome the constraints of the multinomial logit model. Lee et al. [144] use a mixed logit model to investigate passenger's choice of transportation when air transportation faces competition from high-speed rail (HSR). In their work the authors seek to assess changes in passengers' behaviour following the introduction of HSR on Seoul-Jeju route. To do so, they use a mixed logit model which they present as more flexible than a standard logit model, as it can be applied to any random utility model. The random utility approach was introduced by Domencich and McFadden [145] and McFadden [146]. This approach makes it possible to take into account the dispersion of individual preferences and therefore the variability of transport mode choices thanks to a stochastic (random) component. This approach therefore admits that there is no uniformity of choice. The authors highlight that the mixed logit models allow solving the problem of independence of irrelevant alternatives, relaxing this assumption. This grants a stabilization of the results of the model when a new alternative is added to the initial series of possibilities. Finally, because of its ability to overcome the various constraints of the multinomial model, the mixed logit is considered by Greene and Hensher [147] as a model that can considerably improve the behavioural realism in the representation of consumer choices.

The model used by [144], [148]allows them to introduce more than two transport modes, indeed the mixed logit is non-binary. To conduct this study, the authors maximize a utility equation such that:

$$U_m = \alpha_m + \beta_1 TC + \beta_2 TT + \beta_3 Freq + \beta_3 Z$$

where *m* is the mode of transport, U_m is the passenger utility for mode *m*, *TC* the transport cost, *TT* the transport time, *Freq* the frequency for mode *m* and *Z* can be either the safety level of each mode or the duty-free access allowed by each mode. Finally, α_m, β_1, β_2, β_3 and β_4 are the coefficients to be estimated. However, some constraints remain in the mixed logit, notably regarding the input data which must satisfy assumptions such as random utility maximization theory [149].

Through their work, the authors have improved the understanding of passengers' modal choice by adding new variables to the model such as security and duty-free access. The analysis of modal choice with the inclusion of new variables shows passenger's behaviour changes.

In our forthcoming analysis we will test the two different models described above and will determine, depending on the available data which model will be the most relevant to explain passenger choice of transportation modes.

5.1.2 Continuous model

As mentioned in the introduction, continuous models are intended to predict transport demand expressed in terms of quantity demanded, depending on demand factors.

Castillo-Manzano et al. [150] analyse the impact of HSR competition on air travel demand for domestic travel in Madrid Bajaras. They study more precisely the impact of the expansion of an HSR network on air transport in Spain, assessing the substitution path between air and rail transport during the period 1999 to 2012. Their analysis is the perfect example of the use of a continuous model. The authors adopt a dynamic linear regression model formalized by the following equation:

$$planepas_t = \beta_0 + \beta_1 op_{t-1} + \beta_2 hsrpas_t + \beta_3 unemp_t + \beta_4 snow_t + \beta_5 bus_t + \beta\beta_6 popu_t + \sum_{i=7}^{17} \beta_i Seas_{it} + \varepsilon_t$$

where, *planepast* is the number of domestic air passengers at time t at Madrid-Barajas airport; opt_{t-1} is the number of domestic flights at Madrid-Barajas airport in $t-1$, *hsrpast* is the number of HSR passengers in the Spanish railway system at time t, $unemp_t$ is the unemployment rate, $snow_t$ is a dummy variable capturing the impact of the airport paralyzed in January 2009, due to heavy snowfall, $popu_t$ is the population of the provinces connected by HSR at time t, bus_t is a dummy variable that considers the differences between business or trading days and weekends and $Seas_{it}$ is a set of dummy variables for i = 7,…,17 and time t.

Castino-Manzano et al. [150] seek to predict the number of domestic passengers at time t at Madrid Barajas airport thanks to a linear dynamic model. They introduce a number of control variables that traditionally impact the demand for air transport and are used in transport empirical literature: proxy for the size of the market, characteristic of the market, socio-economic shocks etc. By adopting a dynamic model, they increase the robustness and flexibility of their methodology. The advantage of using linear models is that they are simple to implement. The dynamic aspect allows for easier interpretation of the results and avoids the problem of omitted variables.

Static linear regression models need to take into account all changes that may occur during the studied period. The main disadvantage of this is that it makes the model cumbersome and the predictions potentially misleading. The dynamic model therefore takes into account changes during the study period by referring to past data that are time dependent. However, this type of model requires demanding and complicated data to be available, and these data are strategically sensitive for the transport providers. To carry out this type of study, traffic data from the different air and rail operators over the same periods are needed. The required data represent an important barrier to the realization of such a demand analysis.

The second research paper to be discussed here is by Clewlow et al. [151]. Their analysis looks at the impact in Europe of high-speed rail on short-haul air travel demand. The period of analysis, 1995 to 2009, is characterized by the emergence of low cost carriers (LCC) that may add some competitive pressure on air travel demand for major airlines. This is taken into consideration by the authors. Specifically, the study aims to assess the impact of high-speed rail and LCC supplies on air travel demand, and the impact of train travel times, population density, airport characteristics, among others, on substitution between air and rail. The study is based on a panel data set of European passenger traffic from 1995 to 2009. The authors use variance component models to perform their analysis. This type of model will allow us to highlight the characteristics of cities or airports that play a role in the substitution between air and rail. To do this, the model is used on three different scales. The first estimates demand between city pairs, i.e. origin-destination, the second between airport pairs and finally at the airport level. The purpose of this method is to compare the estimates according to the scales used. The authors express a model per scale of analysis, for instance, at the city-pair the model takes the following form:

$$\ln(OD\ Demand_{it}) = \beta_0 + \beta_1 \ln(Rail_{it}) + \beta_2 \ln(X_{it}) + \mu_i + \varepsilon_{it}$$

where, index i denotes city or airport pairs and t is the year, $ln(OD\ Demand_{it})$ is the number of air passengers measured on an origin-destination, $Rail_{it}$ is the rail travel time on the route i, during the period t, is a matrix of control variables that are known to influence air traffic demand: GDP, population, density of population and fuel price. μ_i is a random effect, which only depends on the origin-destination, and ε_{it} is the random error term, that reflects the part of the data not explained by the model. The coefficients are the parameters to be estimated.

This equation is used to study the impact of high-speed rail on air traffic at the origin-destination level. This econometric analysis technique helps understanding substitution effects between air and rail. This type of model is valuable for studying substitution effects and therefore market shares evolution between air and rail transport. However, this type of analysis requires panel data, which is complicated to obtain, because of its strategic issues for transport providers. More generally, transport demand studies are often limited by the availability of data.

The models we have just encountered here appear to be relevant to the Modus project for estimating market share and substitution effects between air and rail. Although these models are very useful and relatively simple to implement in the context of studies such as these, there are still important limitations in terms of the availability of the data needed to make them work.

5.2 Next steps on demand modelling

The literature review of econometric models in Section 5.1 highlights the fact that the model choice is strongly related to the type and quality of data available as well as to the model objectives and expected results. In the scope of Modus, the objective of Task 3.2 is to test the transport demand sensitivity to its drivers in order to assess the evolution of transport modes' market shares in the scenarios to be defined in Task 3.3. These market shares assessments will then be used in work package 4.

Given all these elements, the econometric model that appears being the more adapted for the project will use continuous variables for the demand drivers and will model the sensitivity of transport modes' market share to these drivers. The choice of the econometric model between the continuous ones presented in Section 5.1 as well as its definitive formula will be strongly related to the availability of required data to run the model. In other words, data features and quality are essential to build and assess relevant econometric demand models.

We dedicated a lot of time to identify which databases could be available for Modus. The main difficulty lies in the lack of homogeneity of data between rail and air database that will force us to make some assumptions. An additional difficulty is the absence of available databases on individual characteristics of travellers as well as on their perceptions. It follows that the only demand drivers that will be included in the assessed demand model will be data on supply characteristics as well as national economic data (e.g. GDP coming from the World Bank database).

For each transport mode we therefore need to collect data on demand levels (level of traffic) and data on supply capacity and features for the same period of time.

Considering these constraints, the investigated databases all have data available for the year 2016 on the same European city-pairs. Modus D2.1 deliverable already presented the different databases that could potentially be available; Given all these databases and the constraints on time period (2016) and on city-pairs, the data that are in the current process of collection in the scope of Modus are the following:

<u>Air transport</u>

- OAG data: providing daily supply capacity and features available on city-pairs
- SABRE data: providing yearly traffic available as well as average fares on city-pairs
- Missing data: the daily level of traffic being missing, we will approximate these data by applying the average load factors on each city-pairs by mixing OAG and SABRE data

Rail transport:

- MERITS data: providing daily supply capacity and features available on city-pairs
- Missing data: the daily level of traffic being missing, we will approximate these data by applying the average yearly load factors of rail operators on MERITS data to approximate them

Databases on intermodal trips are unfortunately unavailable while these information could have been very useful for the analysis. We will therefore concentrate our assessment on comparing rail and air transport.

Currently, the datasets that will be used to build and run the model are not all available yet, since some data are still in the acquisition and processing stages. It is therefore too early to present this model as well as the corresponding assessments. The next steps are therefore to

- finalise the data collection,
- clean data and aggregate the data from various sources to build the basis for the econometric model,
- build and run the model to get rail and air transport demand elasticities assessment,
- build scenarios,
- run the model to assess potential markets shares in each of the considered scenarios.

All these results will be presented in deliverable D3.2.

6 Synthesis, Discussion and Next Steps

6.1 Introduction

The objective of this deliverable D3.1 – Modal choice analysis and expert assessment – was the identification and initial high-level assessment of factors that influence the future supply and demand of mobility, and which may exhibit the potential to shift the current landscape of the European transport system. For this purpose, a comprehensive literature review identified a set of high-level as well as detailed drivers of supply and demand. These factors build the main basis for the integration in the Modus modal choice analysis (addressed in D3.2) as well as the passenger mobility modelling (addressed in D4.2) in order to assess the respective impact on future passenger mode choice and market shares of air and rail in different future scenarios.

This analysis has been complemented by an expert survey, to gain initial high-level insight regarding the potential importance of various factors, and by a multimodality workshop, to identify additional factors and acquire a first insight into potential enablers and barriers of future mobility solutions.

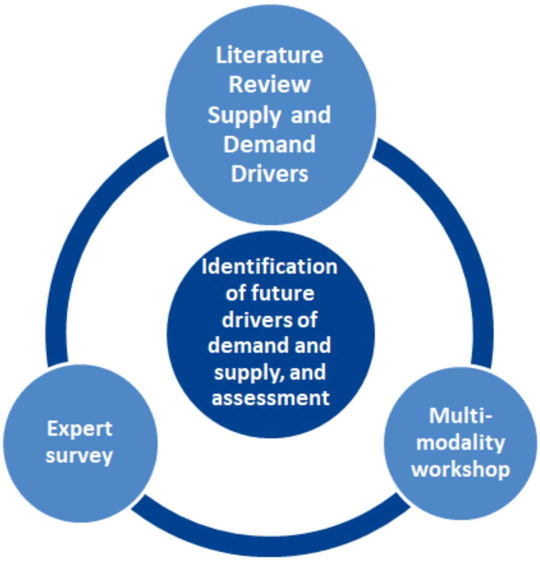


Figure 33: Identification and assessment of future drivers of supply and demand in Modus

Source: own depiction

The following section provides a consolidated overview of these different elements and how these are linked with further work in Modus.

6.2 Consolidation of drivers and discussion

6.2.1 Overview

The detailed analysis and initial assessment of future drivers of supply of and demand for mobility yields a comprehensive list of factors which have to be considered in the assessment regarding their modal choice impact as well as the resulting impact on the performance of the European transport system. Table 17 provides a consolidated overview of these factors and in which part of the analysis these have been discussed. The literature review includes all factors which are currently being discussed as relevant for shaping the future European mobility landscape. The findings from the expert survey and the discussion in the multimodality workshop revealed some additional factors which are highlighted in the table as 'novel identified drivers'.

Table 17: Consolidated drivers for supply and demand

Category	Summarised factors	Literature review	Expert survey	Multimodality workshop
Social	Population (growth, ageing)	x	x	
	Urbanization	x	x	
	Global conflicts and terrorism	x		
	Passengers' expectations	x	x	x
	Health concerns	x	x	
Technological	Fuels & environmental technologies	x	x	
	New propulsion technologies	x	x	
	Capacity & infrastructure	x	x	x
	Information and communication technology (ICT)	x		x
	Artificial intelligence (AI)	x	x	x
	Drones & urban air mobility (UAM) systems	x	x	x
	Safety	x		x
	Security	x		x
Economic	Economic developments (GDP, income)	x	x	
	Price of fossil energy / non-fossil energy	x	x	
	Business models & overall market structure	x	x	x
	Intermodalilty	x	x	x
	Operating costs	x		x
	Operating revenues and profit	x		x
(novel identified driver)	New work		x	
Environmental	Climate change	x	x	
	Natural resources scarcity	x		
	Carbon footprint	x		x
	Environmental values	x	x	x
Political	Travel restrictions	x	x	
	Regulations	x	x	x
	Market openness / Globalisation	x		
Mobility	Travel profiles & personalisation	x		x
	Impaired passenger	x		x
	Tourism	x		
	Perceived travel aspects (e.g. control, information, comfort)	x		x
	Travel information	x		x
	Control	x		x
	Transport time & speed	x		x
	Reliability	x		x
	Accessibility	x		x
	Connections & frequency	x		x

Category	Summarised factors	Literature review	Expert survey	Multimodality workshop
	Interoperability	x		x
(novel identified driver)	Data sharing			x
(novel identified driver)	Covid-19 recovery drivers (e.g. testing, vaccine)		x	
(novel identified driver)	Passengers confidence to re-travel		x	
(novel identified driver)	Long-term resilience		x	x

6.2.2 Supply and demand drivers (literature review)

In total, 66 drivers are identified within the literature review (with some double entries among the sub-reviews), see Section 2. As seen in Figure 34, most drivers are of social (19), economic (16) and technological (13) nature. The identified drivers within the high-level overview (Section 2.2) are balanced among all six STEEP-M categories. Looking more closely at Figure 34, a large amount of social drivers are demand drivers (Section 2.3). This is not a surprise as demand drivers are concerned with the passenger (human) side of mobility and covering naturally various social aspects. On the other hand, a larger number of economic drivers belong to the supply drivers (Section 2.4) as this part of the review is concerned with various cost-related drivers or transport operations, the market structure and available infrastructure.

Conversely, although one STEEP-M category is less presented, e.g. only 5 drivers are political (Figure 34), its impact on the current and future levels, and features, of transport supply and demand can be strong. Within the Modus literature review, all drivers are identified as relevant but further analyses are necessary to quantify the real impact of each determinant. We also discover overlaps between the different sub-reviews. For instance, the level of environmental awareness among passengers is considered as a high-level driver, which gained particular importance within recent years, and is also essential for the detailed reviews and for modelling exercises in the Modus project.

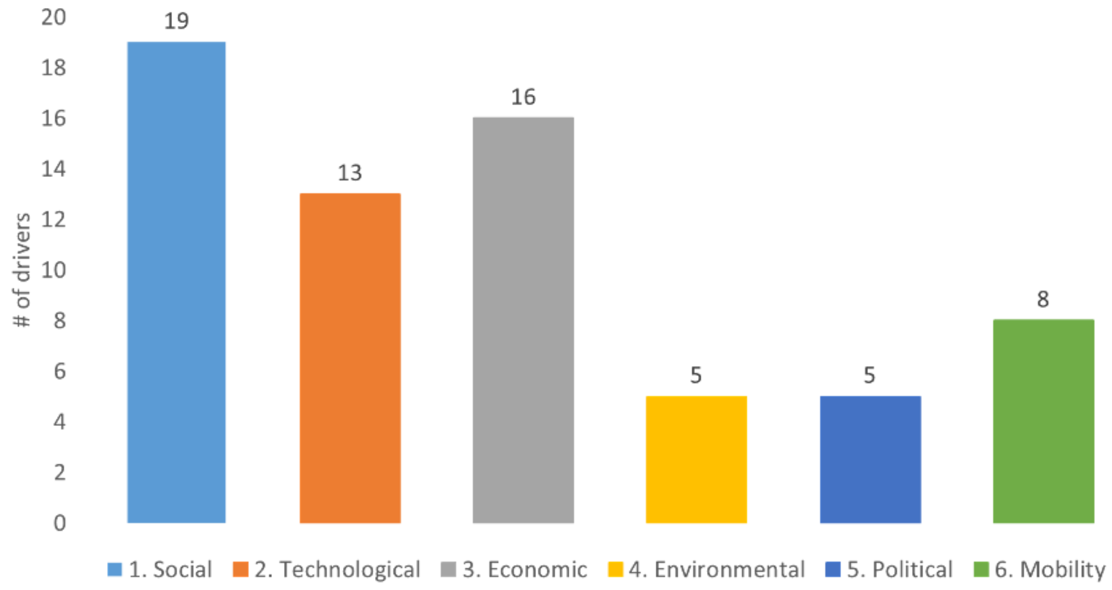


Figure 34: Drivers consolidated from literature review, STEEP-M framework clustering (N=66)

Source: own depiction

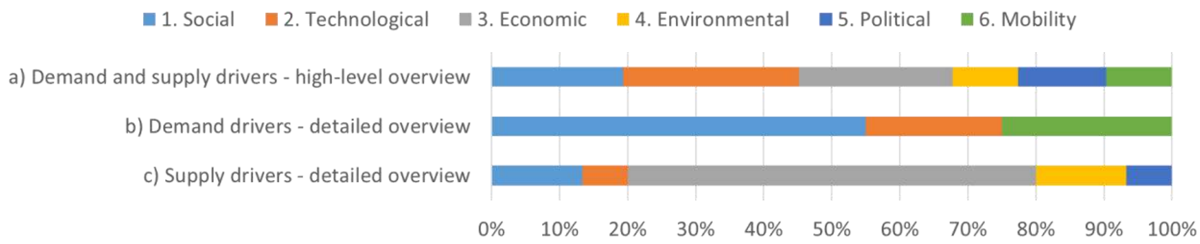


Figure 35: Sub-review clustering STEEP-M framework (averaged to 100% per category)

Source: own depiction

6.2.3 Expert survey

The expert survey complements the comprehensive picture of supply and demand drivers of air and rail transport. Among all the considered drivers, *Economic and GDP change* (e.g. economy is growing, GDP levels are increasing) and *Intermodal integration* and *MaaS* were recognized by the experts in the survey as the two major factors playing a significant role in supply and demand aspects. In addition, the increasing *Passenger environmental attitudes* and *Environment-related regulation* are expected to boost rail supply and demand further. Moreover, in line with the Modus project's goal, combined air-rail travel is believed to grow and is considered the most promising solution by most experts. Most aspects of the air and rail sectors are severely impacted by Covid-19. When assessing the long-term impact of Covid-19 on demand and supply, most experts expect a faster recovery in the rail sector than in the air transport sector. The majority of experts predict rail travel to reach pre-Covid-19 levels in 2022 and air travel to reach pre-Covid-19 levels in 2023 to 2025 (survey conducted at the end of 2020). The involved experts emphasize several drivers for that, including widespread vaccination, rapid testing, and passengers' confidence, which are expected to contribute to promoting recovery of air and rail transport, but are not yet highlighted in the literature.

6.2.4 Multimodality workshop

The Modus multimodality workshop contributed a detailed discussion on specific aspects by experts from different transport domains. This high-level insight unveiled particular issues in terms of strategic and environmental considerations as well as operational collaboration across modes and especially the passenger perspective. The implementation of regulation that will enable better collaboration between modes and ensure a level playing field between modes has been stressed as important. Furthermore, services and products that foster a seamless passenger journey, including information, luggage handling, or security measures, were also highlighted as vital in a future transport system.

6.3 Next steps within Modus

The analysis and assessment conducted in the different sections of this Modus deliverable provides a detailed and comprehensive insight into the drivers that shape the future European transport system, both in terms of supply of and demand for mobility solutions and services. These drivers have been investigated in various levels of detail, via a literature review (Section 2), an expert survey (Section 3), and a multimodality workshop (Section 4), and thus provide input for both the modal choice discussion in Section 5 as well as the upcoming work in Modus, as outlined in Figure 36.

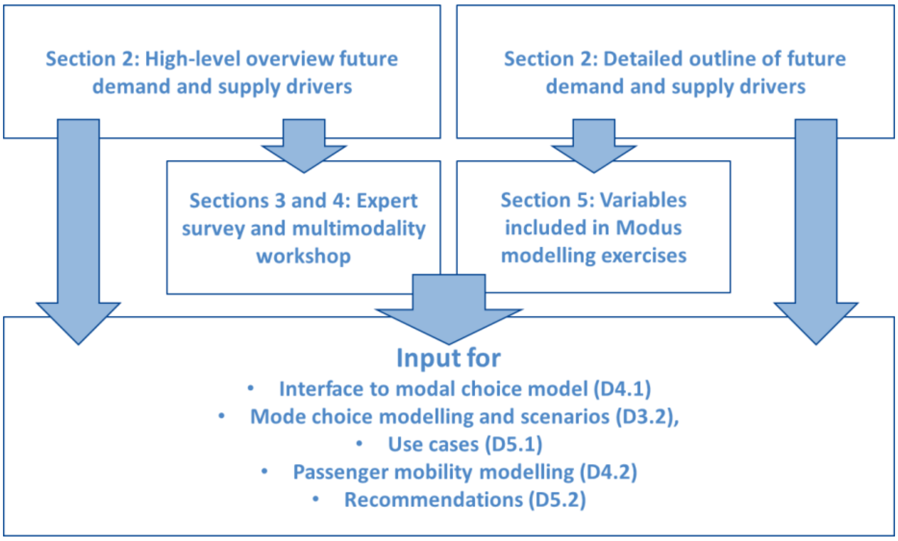


Figure 36: Interlinkages and input for consecutive Modus deliverables

Source: own depiction

The high-level overview of drivers in Section 2 outlines the large variety of factors that need to be considered when moving towards an improved future European transport system. This overview has been the foundation to identify drivers for future mobility supply and demand, which was then partly discussed and assessed in more detail within the scope of the expert survey as well as the multimodality workshop (Sections 3 and 4). Again, these insights in regard to trends and developments yield a valuable contribution for the set-up of the Modus modal choice analysis, use cases, scenarios as well as recommendations for improvement potential at a later stage in the project.

The detailed outline of drivers in Section 2 provides a list of factors which will, when data are available, be integrated in the Modus modelling exercises, for one in the modal choice analysis conducted within the scope of work package 3, and, second, in the passenger mobility modelling (WP4). The outline of these drivers also already includes relevant quantitative measures and respective data sources.

With regard to modelling modal choice in Modus, Section 5 provides an overview and discussion of various econometric models applied in this regard. The literature review of Section 2.3 shows that transport demand is multifactorial. It depends, firstly, on the individual characteristics of users and their psychological and sociological drivers, but also on intrinsic characteristics of heterogeneous transport supply. The econometric model that appears being better adapted for the project will use continuous variables for the demand drivers and will model the sensitivity of transport modes' market share to these drivers. The choice of the econometric model between the continuous ones presented in Section 5 as well as its definitive formula will be strongly related to the availability of required data to run the model.

The next steps will therefore be to:

- finalise the data collection,
- clean data and aggregate the data from various sources to build the basis for the econometric model,
- build and run the model to get rail and air transport demand elasticities,
- build scenarios of evolution of multimodal demand and supply scenarios by 2035+,
- run the model to assess potential market share evolutions of both transport modes in each of the considered scenarios.

Table 18: Forthcoming deliverables and specific input from D3.1

Del. #	Title	Due date	Comments
4.1	Interface to modal choice model: methodology	May 2021	This deliverable will include the data output of the modal choice model and the flow of the data between this and other models developed in Modus, with special focus on the Mercury model and its two independent parts: the gate-to-gate and door-to-gate elements. The output of the modal choice model will be analysed, starting from high-level ideas, and drilling down to low-level implementation details, including a methodology for translation and standardisation of the data so that they can be fed to other models. An overview of other data inputs that will be used to advance the passenger mobility model (Mercury), and in particular its door-to-gate module, will be presented.
3.2	Demand and supply scenarios and performance indicators	June 2021	This deliverable will include the detailed modal choice analysis, using the drivers which are outlined and discussed in D3.1 and the data outlined in D2.1, and hence provide air-rail market shares. Different scenarios will be developed to reflect potential future paths of development of the European transport sector. The modal choice model will be applied across the scenarios, with sensitivity analyses, resulting in gross estimations of modal market shares on city pairs, and hence providing further input to WP4. Furthermore, this deliverable will contain the definition of various performance and connectivity indicators, to be further applied in the assessment in WP5.
5.1	Definition of use cases	June 2021	This deliverable describes the identified use cases, the relevance across the different scenarios identified in WP3, and details the parameters to be analysed in the quantitative and qualitative

Del. #	Title	Due date	Comments
			assessment of Tasks 5.2 and 5.3. A set of specific use cases will be identified and detailed here, considering the high-level strategic ambitions and goals of European transport. These use cases may relate to specific processes, such as passenger flows and dwell times at airports, and transfer between modes, or the integration of ticketing options across various transport modes, for example.

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Appendix A Supply and Demand Drivers – High-Level Overview

STEEP-M	Sources	Factor	Demand driver	Supply driver	Definition	Indicators	Data
Social	• [2]–[5]	**Population change (size)**	x		e.g. population growth due to higher birth rates and greater life expectancy	• overall population growth (%) • fertility rate (%) • projected population growth	Eurostat (https://ec.europa.eu/eurostat/de/home) United Nations (https://population.un.org/wpp/) The World Bank (https://data.worldbank.org/)
	• [2], [9], [10], [13], [152]	**Population change (ageing)**	x		e.g. changing age distribution; persons with reduced mobility; increasing people become economically inactive	• median age (in yrs.) • old-age dependency ratio (OADR) (% of working-age population)	Eurostat (https://ec.europa.eu/eurostat/de/home) United Nations (https://population.un.org/wpp/) The World Bank (https://data.worldbank.org/)
	• [153]	**Immigration**	x		e.g. immigration into Europe from other regions	• #of immigrants	Eurostat (https://ec.europa.eu/eurostat/de/home) The World Bank (https://data.worldbank.org/)
	• [2], [4], [7]	**Urbanisation**	x	(x) in terms of infrastr.	e.g. more people living in urban/ suburban sprawl; need to connect rural areas and urban/ suburban sprawl	• degree of urbanisation • people living in urban sprawl / population density (in % of total population)	Eurostat (https://ec.europa.eu/eurostat/de/home) United Nations (https://population.un.org/wpp/) The World Bank (https://data.worldbank.org/)
	• [76]–[79]	**Health concerns**	(x) in terms of new guidelines	x	e.g. concerns on the passenger side regarding infectious disease and exposure during travel	• passenger survey data	n/a
	• [15], [16], [18], [20]	**Global conflicts and terrorism**		x	e.g. affecting travel demand and tourism due to terrorism and other conflicts	• #of global conflicts • #of terroristic attacks	CARTO: The World's Conflicts map https://emmeline.carto.com/viz/b69015da-136a-11e5-a64a-0e43f3deba5a/public_map Global Terrorism Database (GTD) https://start.umd.edu/gtd/
Techno-logical	• [49], [63]–[66]	**Fuels & environ-ment. Techno-logies**		x	alternative fuels; liquid natural gas; hydrogen; vehicle/airframe design; operational systems	• #of patents; • degree of "*sustainable aviation fuels*" (SAF)-usage • degree of propulsion developments • engine emissions	ICAO Aircraft Engine Emissions Databank (https://www.easa.europa.eu/domains/environment/icao-aircraft-engine-emissions-databank) International Energy Agency (IEA) database (https://www.iea.org/)

STEEP-M	Sources	Factor	Demand driver	Supply driver	Definition	Indicators	Data
	• [63], [64], [66]–[69]	**New propulsion techno-logies**		x	e.g. hypersonic (air); hyperloop (ground); (hybrid)(electric) engines	• #of patents • commercial usability • market penetration • engine emissions	ICAO Aircraft Engine Emissions Databank (https://www.easa.europa.eu/domains/environment/icao-aircraft-engine-emissions-databank)
	• [2], [31], [55]	**Capacity manage-ment & control systems**		x	e.g. automation; autonomous control/separation (private/public vehicles); flow control; dynamic information; terrestrial/satellite wireless comms (e.g. 5G) & signalling; enabled through data sharing; ATM at airports		
	• [1], [2], [56], [154]	**Commu-nication Techno-logies**	x		e.g. messenger applications such as WhatsApp or Threema; videoconferencing; teleworking such as Zoom, Webex, MicrosoftTeams; on-board wifi	• #of users (in m) • #of tools in the market	International Energy Agency (IEA) database (https://www.iea.org/) The World Bank (https://data.worldbank.org/)
	• [27], [85]	**Security-focused techno-logies**		x	all actions that need to be necessary to keep the transport system safe e.g. cybersecurity; blockchain; biometrics; technological developments for pax side: (e.g. security, payment, tracking…);		
	• [21]–[23], [25], [26], [62]	**Artificial intelligence (AI)**		x	e.g. the advancement of machine learning (ML)models, robotics, predictive control, Internet of Things (IoT)	• accuracy of models • computing time (in sec. or min.)	
	• [32], [32]–[36]	**Drones & urban air mobility**		x	manned and unmanned	• #of patents • #of UAM companies / start-ups	Crunchbase start-up database (investments, deals, fundings series): https://www.crunchbase.com/

STEEP-M	Sources	Factor	Demand driver	Supply driver	Definition	Indicators	Data
		(UAM) systems					Pitchbook start-up database (investments, deals, fundings series): https://pitchbook.com/ Owler Search (company data and news): https://www.owler.com/search
	• [20], [27]–[30]	**Safety**	x		e.g. creating a safe transport system throughout for passengers and taking all actions needed to prevent any kind of accidents or errors, e.g. also in terms of aviation security measurements post-Covid	• #of accidents • #of fatalities • Other safety indexes, such as the UIC (2020a) Safety Index	Transport accident reports Aviation: ICAO (2019) Accident Statistics https://www.icao.int/safety/iStars/Pages/Accident-Statistics.aspx Railway: UIC Safety Database (UIC-SDB) (2021) https://safetydb.uic.org/
Economic	• [5], [37], [38]	**Economic / GDP change growth**		x	e.g. the GDP (growth) rate per country	• total GDP per country	The World Bank: GDP (current US$) country level (https://data.worldbank.org/indicator/NY.GDP.MKTP.CD) Eurostat (https://ec.europa.eu/eurostat/de/home) The World Bank (https://data.worldbank.org/) Happy Planet Index (HPI) (http://happyplanetindex.org/)
	• [4], [11], [40]–[43]	**Change in disposable income / permanent income**	x		e.g. increasing financial resources to travel per inhabitant or per household	• GDP per capita (as proxy for income) • unemployment rate, inflation rates • Purchasing Power Standards (PPS)	The World Bank: GDP per capita growth (annual %) country level (https://data.worldbank.org/indicator/NY.GDP.PCAP.KD.ZG) eurostat (https://ec.europa.eu/eurostat/de/home) The World Bank (https://data.worldbank.org/)
	• [5], [45], [148]	**Price of fuel / Price of fossil energy (kerosine & diesel)**		x	e.g. high volatility in fuel prices and degree of uncertainty; could be similar to energy demand	• in US-*$/Gallone* • in *€/liter*	The World Bank: Pump price for diesel fuels 8US$ per liter) country level (https://data.worldbank.org/indicator/EP.PMP.DESL.CD)

STEEP-M	Sources	Factor	Demand driver	Supply driver	Definition	Indicators	Data
							International Energy Agency (IEA) database (https://www.iea.org/)
	• [66]	**Price of non-fossil energy**		x	e.g. high volatility in fuel prices and degree of uncertainty; could be similar to energy demand	• in €	International Energy Agency (IEA) database (https://www.iea.org/)
	• [48]–[51], [155] •	**Evolving business models & market structures**		x	e.g. ownership; alliances (airline-airline, rail-rail, airline-rail, etc.) hubbing; increasing number of merges and alliances even cross-modal	• business model convergence rate • M&A development over time • European Regional Competitiveness Index (2019)	Daft, J., & Albers, S. (2013). A conceptual framework for measuring airline business model convergence. *Journal of Air Transport Management*, *28*, 47-54. European Regional Competitiveness Index (2019): https://ec.europa.eu/regional_policy/en/information/maps/regional_competitiveness/#1
	• [2], [47], [53], [54]	**Intermodal cooperation and ticketing; MaaS**		x	offering tailored transport with the use of single-ticketing, joint offers and pricing; multimodal (air-bus); incl. airport access/egress, integrated ticketing	•	
	• [27], [55]	**Changes in reliability**	x		expectation that services will run on-time, also supported by digitalisation; schedule and connectivity data; service recovery apps	• delayed trips	
Environmental	• [2], [57]–[60], [62]	**Climate change**		x	e.g. stronger weather events; warmer northern Europe	• in temperature • total greenhouse gas emissions (kt of CO_2 equivalent)	The World Bank (https://data.worldbank.org/) GISTEMP Team, 2021: *GISS Surface Temperature Analysis (GISTEMP), version 4*. NASA Goddard Institute for Space Studies. Dataset accessed 20YY-MM-DD at https://data.giss.nasa.gov/gistemp/.

STEEP-M	Sources	Factor	Demand driver	Supply driver	Definition	Indicators	Data
	• [2], [70]–[73]	**Environ-mental attitudes and willingness to change behaviour**	x		e.g. passengers have increased environmental awareness and behave accordingly taken personal actions (e.g. pax more willing to reduce air travel, paying for a carbon-offsetting or using substitutes)	• passenger survey data • #of flights per year and km per pax • carbon offset purchases	EcoPassenger (2020) personal CO_2-emission metric per mode
	• [57], [61]	**Natural resources scarcity (NRS)**		x	e.g. natural lack of resources such as water, oil or metals which can impact many business acitivities on the supply side	•	
Political	• [74], [75], [77]–[79]	**Travel restrictions**	(x)	x	as currently experience due to the Covid-19 pandemic or political restrictions; can be both supply and demand driver (new driver!); Supply restrictions due to Covid-19	• #of countries facing restrictions	Worldwide: IATA (2021). Covid-19 travel regulations map. https://www. iatatravelcentre.com/world.php. EU-level: European Union (2021), re-open EU. https://reopen.europa.eu/en
	• [60], [81], [82]	**Regulatory change - passenger rights, various modes**		x	e.g. air (Reg. 261) and rail (Reg. 1371)	• legal documents • Level of disruption • Air passengers' perspective on their rights (passenger survey)	e.g. legal documents, political strategies and agendas • The European Green Deal (rail and aviation) European Commission (2019b) Flightpath2050 (aviation) European Commission (2011)
	• [31], [60], [82]	**Regulatory change – environ-mental**		x	e.g. fuel duties; short-haul flight restrictions; CO_2 and non CO_2 emissions reduction, European Green Deal	• legal documents • environmental targets in % of reducing CO_2 and non-CO_2 emissions • environmental targets in % of noise reduction (airports and railway stations)	e.g. legal documents, political strategies and agendas • The European Green Deal (rail and aviation) European Commission (2019b)

STEEP-M	Sources	Factor	Demand driver	Supply driver	Definition	Indicators	Data
							• Flightpath2050 (aviation) European Commission (2011)
	• [83], [84]	**Trade policy / Globalisation**	x		Development of global trade in terms of trade centers, extent of international trade and degree of of cooperation between different companies from countries, especially due to new/removed new/removed trade barriers and tariffs; intercultural exchange between countries	• KOF Index of Globalisation	KOF Globalisation Index from ETH Zurich (2021) https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html
Mobility	• [2], [88], [89], [152]	**Change in tourism patterns**	x		e.g. reject mass tourism; niche tourism; restriction of places of interest; virtual tourism	• passenger survey data • in people travelling / year	
	• [12], [85], [85], [87], [88], [91], [152]	**Diverse travel needs and personalisation**		x	travel profiles are increasingly diverse which increases the need to personalise journeys (increased personalisation)	• passenger survey data	
	• [90], [91], [156]	**Travel purpose**	x		refers to the purpose of travel: private (visiting friends and relatives (VFR), health, religion, leisure, recreation and holidays and other) vs. business travel	• Binary variable (p vs. b) • price elasticity (p vs. b)	business vs. economy seats per flight / route (OAG); ticket class (SABRE)

Appendix B Questionnaire Expert Survey

Tackling the future of mobility: welcome to 2040!

Background and motivation

This survey is part of the EU-H2020-SESAR 'Modus' project[1]. The project was launched in June 2020, and the consortium consists of seven members: Bauhaus Luftfahrt e.V., École nationale de l'aviation civile, the University of Westminster, Fundacion Instituto de Investigacion Innaxis, International Union of Railways, Skymantics Europe SL , and EUROCONTROL – the European Organisation for the Safety of Air Navigation.

The main objective of the Modus project is the analysis of the performance of the overall transport system by considering the entire door-to-door journey and assessing the role of air transport within an integrated, intermodal approach. For this purpose, Modus identifies and assesses drivers for passenger demand for, and supply of, mobility in terms of their impact on passenger modal choice. This enables the development of multiple scenarios of future mobility paths, taking into account aspects such as new regulatory contexts meeting new environmental standards, or new transport operators' business models, covering a **time horizon of 2040+ (i.e. well beyond the current COVID-19 crisis)**.

The project provides an **integrated modelling approach towards the European transport system, including both air and rail transport**, to enable a thorough assessment of the gaps and potential solutions required to meet European high-level objectives. It provides tools and insights for decision-makers in moving towards the future vision of the European transport system, also strongly supported by the inclusion of an intermodal Industry Board and other relevant experts.

1) The Modus project received funding from the European Union's Horizon 2020 – SESAR research and innovation programme on the topic SESAR-ER4-10-2019 "ATM Role in Intermodal Transport" under Grant Agreement No. 891166. More information can be found here: https://modus-project.eu/

Purpose of the questionnaire

The following questionnaire is concerned with supply and demand drivers relating to the **door-to-door (D2D) travel chain, including air and rail travel, in 2040** (both in the context of business and leisure trips). We would like to take a **long-term perspective of European travellers** (cargo is not within scope). The focus is on multimodal transport that includes as a main segment either rail or air transport (see figure below). Other transport modes such as public transport are considered as access and egress modes to either the airport or the rail station. The focus is on travel segments within Europe as part of a multimodal

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journey, e.g. a passenger journey from Paris to Berlin, or from Helsinki to Lisbon.

The purpose of the questionnaire is to capture the expertise of various experts from different transport sectors with regard to possible futures for European travellers and factors with the most influence on the evolution of travel. The survey provides inputs to the Modus project about future transport drivers, for modelling and simulating future transport performance and building informed recommendations to decision-makers. It also includes the possibility for you to participate in an online workshop in early 2021 allowing further exploration of the most important aspects identified (in case of interest please let us know via e-mail modus@bauhaus-luftfahrt.net).

The questionnaire will take about **15 - 20 minutes** to complete in total. Your expert opinion and contribution is very much appreciated and will be of great value for the overall project objectives.

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Tackling the future of mobility: welcome to 2040!

Data protection

The survey is completely anonymous. It is part of the EU-H2020-SESAR Modus project. The data acquired from the survey will be used solely for the purposes of the Modus project and will not be shared with any other party. The results may be published in project reports, journal articles, conference presentations, and via other modes of scientific exchange and dissemination.

Informed consent by participants

- I am aware of the main aspects of the online expert survey for the above SESAR 2020 activity.
- I understand that my participation is entirely voluntary. I can refrain from participating in the online expert survey at any time, without any penalty or prejudice.
- Should I not wish to answer any particular question(s), I am free to decline without any penalty or prejudice.
- I will not receive any compensation or incentive for having taken part in this online expert survey.

* Do you agree to the above terms? By clicking Yes, you consent that you are willing to answer the questions in this survey.

○ Yes

○ No

RESPONSIBLE FOR DATA TREATMENT IN ACCORDANCE TO THE GDPR (CONTROLLER)
Bauhaus Luftfahrt e.V., Willy-Messerschmitt-Str. 1, 82024 Taufkirchen, Germany.
Data Protection Officer: Michaela Richter (Bauhaus Luftfahrt e.V.; michaela.richter@bauhaus-luftfahrt.net)

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Tackling the future of mobility: welcome to 2040!

Section 1

*Kindly note this is the main question in our questionnaire, in which we have consolidated several elements: many thanks for your time and patience in completing it. We suggest you use the **landscape mode** if you are using a mobile phone to answer this question.*

Which factors do you think will have a significant impact on the supply and demand for air and rail transport by 2040? Regarding **social, technological, economic, environmental, and political** aspects, please choose from the following dropdown list to assess the impact of each driver/factor.

The scales of driver effect are as follows:
+3 = strong increase
+2 = medium increase
+1 = weak increase
0 = no significant effect
-1 = weak decrease
-2 = medium decrease
-3 = strong decrease
n/a = don't know / cannot make an assessment

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Social

	2040 SUPPLY Air travel	2040 SUPPLY Rail travel	2040 DEMAND Air travel	2040 DEMAND Rail travel
Population change (size) (e.g. higher birth rates; greater life expectancy)				
Population change (ageing) (e.g. changing age distribution; persons with reduced mobility)				
Immigration (e.g. into Europe)				
Urbanisation (e.g. more people living in urban/ suburban areas)				
Change in tourism patterns (e.g. change in mass tourism vs. alternative forms of tourism)				
Health concerns (e.g. infectious disease; exposure during travel)				

Please feel free to comment on the rating above and/or suggest any other relevant factor(s) and its (their) effect scale(s).

Tackling the future of mobility: welcome to 2040!

Section 1

The scales of driver effect are as follows:
+3 = strong increase
+2 = medium increase
+1 = weak increase
0 = no significant effect
-1 = weak decrease
-2 = medium decrease
-3 = strong decrease
n/a = don't know / cannot make an assessment

Technological

	2040 SUPPLY Air travel	2040 SUPPLY Rail travel	2040 DEMAND Air travel	2040 DEMAND Rail travel
Fuels & environmental technologies (e.g. alternative fuels; liquid natural gas; hydrogen; vehicle/airframe design; operational systems)				
New propulsion technologies (e.g. hypersonic (air); hyperloop (ground),; (hybrid)(electric) engines)				
Capacity management & control systems (e.g. automation; autonomous control/separation (private/public vehicles); flow control; dynamic information; terrestrial/satellite wireless comms (e.g. 5G) & signalling)				
Communication technologies (e.g. WhatsApp; Zoom; videoconferencing; teleworking; on-board wifi)				
Security-focused technologies (e.g. cybersecurity; blockchain; biometrics)				

	2040 SUPPLY Air travel	2040 SUPPLY Rail travel	2040 DEMAND Air travel	2040 DEMAND Rail travel
Artificial intelligence (e.g. machine learning, robotics, predictive control, Internet of Things)				
Drones & urban aerial mobility systems (manned and unmanned)				
Changes in reliability (incl. digitalisation; schedule and connectivity data; service recovery apps)				

Please feel free to comment on the rating above and/or suggest any other relevant factor(s) and its (their) effect scale(s).

Tackling the future of mobility: welcome to 2040!

Section 1

The scales of driver effect are as follows:
+3 = strong increase
+2 = medium increase
+1 = weak increase
0 = no significant effect
-1 = weak decrease
-2 = medium decrease
-3 = strong decrease
n/a = don't know / cannot make an assessment

Economic

	2040 SUPPLY Air travel	2040 SUPPLY Rail travel	2040 DEMAND Air travel	2040 DEMAND Rail travel
Economic / GDP change (e.g. economy is growing, GDP levels are increasing)				
Change in disposable income (e.g. increasing financial resources to travel)				
Price of fossil energy (kerosine & diesel) (incl. price volatility)				
Price of non-fossil energy (incl. price volatility)				
Evolving business models & market structures (e.g. ownership; alliances (airline-airline, rail-rail, airline-rail, etc) hubbing)				
Intermodal integration; 'mobility as a service' (incl. airport access/egress, integrated ticketing)				

Please feel free to comment on the rating above and/or suggest any other relevant factor(s) and its (their) effect scale(s).

Tackling the future of mobility: welcome to 2040!

Section 1

The scales of driver effect are as follows:
+3 = strong increase
+2 = medium increase
+1 = weak increase
0 = no significant effect
-1 = weak decrease
-2 = medium decrease
-3 = strong decrease
n/a = don't know / cannot make an assessment

Environmental

	2040 SUPPLY Air travel	2040 SUPPLY Rail travel	2040 DEMAND Air travel	2040 DEMAND Rail travel
Climate change (e.g. stronger weather events; warmer northern Europe)				
Passenger environmental attitudes (e.g. passengers experience a change in regard to environmental awareness and adjust behaviours)				

Please feel free to comment on the rating above and/or suggest any other relevant factor(s) and its (their) effect scale(s).

Tackling the future of mobility: welcome to 2040!
Section 1

The scales of driver effect are as follows:
+3 = strong increase
+2 = medium increase
+1 = weak increase
0 = no significant effect
-1 = weak decrease
-2 = medium decrease
-3 = strong decrease
n/a = don't know / cannot make an assessment

Political

	2040 SUPPLY Air travel	2040 SUPPLY Rail travel	2040 DEMAND Air travel	2040 DEMAND Rail travel
Regulatory change - passenger rights, various modes (e.g. air (Reg. 261) and rail (Reg. 1371))				
Regulatory change - environmental (e.g. fuel duties; short-haul flight restrictions; European Green Deal)				

Please feel free to comment on the rating above and/or suggest any other relevant factor(s) and its (their) effect scale(s).

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Tackling the future of mobility: welcome to 2040!
Section 2

How do you assess the **future demand** for **air and rail travel** by 2040, in Europe?

	Growing	Relatively stable	Declining	Don't know
Air travel (leisure purpose)				
Air travel (business purpose)				
Rail travel (leisure purpose)				
Rail travel (business purpose)				
Combined air-rail solutions				

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Tackling the future of mobility: welcome to 2040!
Section 3

How do you assess the future development of the **supply in the air and rail sector** by 2040, in Europe?

	Growing	Relatively stable	Declining	Don't know
Air transport supply	○	○	○	○
Rail transport supply	○	○	○	○
Combined air-rail-solutions	○	○	○	○

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Tackling the future of mobility: welcome to 2040!
Section 4

How do you assess the **long-term impact of COVID-19** on future transport demand and supply, in Europe?

Please leave it empty if you don't know or cannot make an assessment.

Air transport sector

When do you think air traffic will recover and reach pre-COVID-19 levels? (in years)

What are the main drivers for reaching that level, e.g. widespread vaccination?

Which aspects or areas in the air transport sector do you think will be most affected in the next 10 years?

Rail transport sector

When do you think rail transport will recover and reach pre-COVID-19 levels? (in years)

What are the main drivers for reaching that level, e.g. widespread vaccination?

Which aspects or areas in the rail transport sector do you think will be most affected in the next 10 years?

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Section 5: Demographic questions

Which industry and/or transport mode are you working with? *Please select the most applicable one(s).*

- ☐ Airport
- ☐ Airline
- ☐ Rail
- ☐ Public Transport
- ☐ Manufacturer
- ☐ Consultant
- ☐ Research facility or university

Other (please specify)

What is your position?

- ○ Employee
- ○ Middle Management
- ○ Top Management
- ○ Board Member or Executive
- ○ Researcher
- ○ Self-employed
- ○ Consultant

Other (please specify)

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Years of experience in transport/related sector

How would you assess your expertise in answering these questions?

- ○ Not confident
- ○ Quite confident
- ○ Confident
- ○ Highly confident

Other (please specify)

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Thank you for participating in this survey!

If you have any other comments or requests please send an e-mail to: modus@bauhaus-luftfahrt.net. We are happy to engage in further exchange with you on these topics.

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Appendix C Workshop: Group Cluster Results

Topic 1: What are infrastructure needs and feasibility?

Group 1

No.	Cluster name	Definition (This cluster is mainly about…)
1	Economics	Multimodal trip pack creation & insurance
2	Luggage handling infrastructure:	Passengers expectations on luggage multimodal transport
3	Collaborative processing across modes	Coordination of actors across modes for a D2D passenger experience (air-rail-urban transport)
4	Passenger planning (ICT needs)	Multimodal info to passengers in planning & execution
5	Passenger journey experience	Integrated tickets; Fluid & Consistent travel info and facilities across modes on multimodal trip & countries (e.g. Covid); passenger diversity (disabled, languages, infrequent travellers)
6	Airport design	Access to several modes at airports, design for more passengers
7	Information/data sharing	Coordination between modes
8	Environment	Useless trips & noise @ airport
9	Connectivity	UAM-rail-train at multimodal hubs; infra funding; parking; public links airports to city-centre
10	Flexibility - resilience	Disruption for passengers and flexibility to recover – buffer time

Group 2

No.	Cluster name	Definition (This cluster is mainly about…)
1	IT System D2D / passenger data sharing / trust between modes / collaboration	The D2D development requests data availability and data sharing, collaboration between different transport modes and adapted policies are necessary.
2	Information to improve passenger experience	Real time, user-friendly, accessible and accurate information would improve passenger experience before and during his trip. Transfer time, development of intermodal hubs between modes of transport and information in case of disruptions are some key elements on the subject.
3	Infrastructure capacity	Infrastructures should avoid bottlenecks and make intermodality possible with better hubs and connexions, connecting air and rail with the regional, national and international territory with dedicated policies and funds that would allow it, taking in account new technologies and sustainable issues.

4	Complementarity between air & rail for security	Complementary security policy between air and rail is important to reduce administrative burden.
5	Ticketing interoperability	Ticketing interoperability between air and rail is essential to improve D2D passenger experience and it has to be flexible enough in case of disruption.
6	Luggage chain	Operational and security alignment on luggage handling across air and rail systems is important to enable seamless, intermodal and traceable solutions.

Topic 2: Which business models can support and enable multimodality?

Group 3

No.	Cluster name	Definition (This cluster is mainly about…)
1	Improved stakeholder stress & inclusivity	Improving the journey experience for the passenger, delivering better confidence for all stakeholder types
2	Intermodal transfer accessibility and efficiency	Improving connection times and reliability at cross-modal interfaces
3	Provision of a seamless, single booking tool	Having single tools / booking services whereby a full D2D journey may be booked
4	Regulation to ensure level playing field for service providers	Preventing market dominance or uncompetitive pricing from limited providers, not limiting market access for others
5	Integrated dynamic capacity	Ensuring that capacity across modes is integrated and responsive to real-time demand and changes
6	Requirement for integrated, private data	All service providers are able to sell capacity into integrated booking systems, but retain their own supply privacy
7	Better passenger disruption services & tools	E.g. enabling passengers to re-book and re-plan during disruption (further developing existing tools)

Group 4

No.	Cluster name	Definition (This cluster is mainly about…)
1	Financing infrastructure sustainability	The need of financing/investing on infrastructure (consideration of public/private cooperation)
2	Passenger flow at airport	The role of the airport as a connection hub managing flow of passengers.
3	ICT on D2D	Role of ICT companies on access/egress full D2D trip.
4	Regulatory framework	The role of standardisation, regulation environment, ticketing
5	Air-rail cooperation	Sharing/agreeing on market short-haul/etc.
6	Air-rail competition	Keeping competition on links
7	Data sharing and management	Data sharing between stakeholders (rail/air)

Topic 3: What do passengers of the future look like in terms of personalisation, travel services?

Group 5

No.	Cluster name	Definition (This cluster is mainly about…)
1	Journey planning	How to improve the D2D options/information for the multimodal travel for passengers
2	Booking and ticketing	Offering one ticket for the multimodal trip
3	Regulations	The need for multimodal regulations
4	Information on disruption	The information for passengers on disruptions
5	Security	Streamlining security requirement between modes
6	Network integration	The integration of networks and timetables between modes
7	Price and cost	The process for establishing prices based on costs of travel of the different transport modes
8	Accessibility and comfort	Providing better access and comfort

Group 6

No.	Cluster name	Definition (This cluster is mainly about…)
1	Ticketing innovations:	Single ticketing; MaaStickets, one stop shop
2	Seamless and multimodal connections	Reducing D2D travel time, seamless travel, travel costs, multimodal offers
3	Green travel	Transparency and information, eco-friendly modes along D2D
4	Travel planning	Planning & manage disruptions for demand side
5	Personalisation of travel	Inclusion, personal preferences, peace of mind, safety