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Future multimodal mobility scenarios within Europe

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Abstract

The European transport system faces multiple pressing challenges, including the need for significant emissions reduction in the sector and the provision of a seamless, multimodal journey to travellers. In order to address these challenges, a thorough understanding and assessment of different development pathways are required. This paper elaborates on four different scenarios developed within the scope of the Modus project. Based on these as well as additional insights from experts of the air and rail sector, initial implications for emissions reduction potential, travel times, or technological options are discussed.

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Keywords: Multimodal transport; scenario development; air-rail cooperation; connectivity

Nomenclature

ATM	Air traffic management
EU	European Union
GDP	Gross domestic product
GDPR	General Data Protection Regulation
HSR	High-speed rail
NUTS	Nomenclature of territorial units for statistics
PKM	Passenger kilometres
UAM	Urban air mobility
UN	United Nations

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1. Introduction

The European Smart and Sustainable Mobility Strategy (European Commission, 2020), in line with the goals of the European Green Deal, outlines and discusses measures and policies to reduce transport's greenhouse gas emissions by 90% by 2050. Current discussions on effective abatement measures include, among others, the interaction between air and rail, and whether a shift from air to rail in the short-haul market segment can contribute to the transport sector's emission reduction goals. In this context, manifold aspects have to be considered, including the assessment of the external costs of future infrastructure investments, noise exposure, capacity availability, and the integration of new technology options resulting in efficiency improvements in both sectors. Furthermore, the strategy states that solutions shall be made available within a fully integrated and seamless multimodal transport system. The need for a seamless and hassle-free journey, increasing environmental awareness, regulatory measures, or capacity shortages across different modes, therefore, makes the evolution of European demand for mobility a significant challenge to predict. Among others, the overall performance of the (future) European transport system will strongly depend on the alignment and optimisation of multimodal transport.

In 2019, intra-EU-27 rail and air traffic had a market share of 7% and 9.7%, respectively, considering all distances and modes of transport (European Commission, Directorate-General for Mobility and Transport, 2021). Overall, rail traffic has been increasing by 34.8% in total between 1995 and 2019, compared to air traffic growth of 145.7%. In absolute terms, air transport constituted 582.9 billion passenger kilometers (PKM) in 2019, rail transport 421.4 billion PKM. In 2000, the share of high-speed rail (HSR) in overall rail transport was 17.4% and grew to 31.3% in 2019. Considering this background, the development of future scenarios can shed light on the coming changes and function as a tool to support policy and strategy-making. The four scenarios developed in the Modus project, considering a time horizon of 2040+, aim at exploring how air traffic management (ATM) and air transport can better contribute to improving travellers' multimodal journeys, at the same time exploring the impact on the performance of the joint air-rail transport system.

2. Multimodal scenarios for European transport

The Modus scenarios are the result of the assessment of European high-level mobility objectives, strategic research agendas, existing scenario studies, and the review of investment and deployment strategies in the air and rail sectors. The four scenarios are described in Section 2.1, each listing high-level objectives and studies considered in their development. The scenarios have been discussed with the Modus industry board, which contain both railway and aviation experts (see Section 3.2). In line with European high-level mobility objectives, those outlined in Table 1 play an essential role and are considered for scenario development.

Table 1. European high-level mobility goals.

Connectivity	This goal includes the reduction of travel time and the connection of remote regions.
Environmental impact	The reduced reliance on fossil fuels, reduction of CO_2 emissions, and internalisation of external costs are addressed.
Integration of additional demand	Meeting increasing transport demand by adjusting and extending capacities and aiming at a more efficient resource allocation within the transport network are important in this category.
Technological innovation and (widespread) implementation	Goals relating to this topic include the development of fuel-efficient, hydrogen-powered, and (hybrid-)electric aircraft and bringing these into operation through continued fleet renewal, to ensure that low and zero emission technology options are deployed, including through retrofitting and appropriate renewal schemes in all transport modes.

2.1. Scenario description

Scenario 1, Pre-pandemic recovery, is a baseline against which the other three scenarios are compared. Within this scenario, it is assumed that the European transport market will recover to pre-crisis levels (2019) and that the air transport and railway network structure will remain similar to today. Furthermore, the implementation of innovative technologies, and market-based measures, will facilitate the reduction of emissions in the transport sector. (EUROCONTROL, 2018; EUROCONTROL, 2021; IATA, 2021)

Compared to this, in ***Scenario 2, European short-haul shift***, a significant share of short-haul air traffic is replaced by cooperation between rail and air, which leads to a reduction in overall air traffic on short-haul routes in Europe. In this scenario, a high-quality transport network with HSR services on short-haul distances is established, and aviation services improve the coverage of long-haul routes. Scenario 2 assumptions include that by 2030 HSR traffic will double (this mainly concerns major links inter- and extra-EU) and that scheduled travel of under 500 kilometres should be carbon neutral within the EU. The relevance of rail increases significantly in the segment between 200 to 1,500 kilometres. Furthermore, there is an increased level of cooperation between air and rail to provide both door-to-door solutions and efficient connectivity of European regions (European Commission; European Commission; European Commission, 2019; European Commission, 2020; NLR & SEO, 2021; ERRAC, 2014; Shift2Rail, 2020; CER, 2020; European Commission, 2011; European Environment Agency, 2020; Roland Berger & UIC, 2021; Platform of Rail Infrastructure Managers in Europe (PRIME), 2018; Ruijters, 2021).

In ***Scenario 3, Growth with strong technological support***, high growth rates in the transport sector until 2040 are assumed, which significantly exceed that in the baseline scenario. As a reference for an upper limit for intra-European annual air traffic growth, the Boeing market forecast for 2020 to 2039 is considered. This scenario emphasises the uptake of technological innovations to both reduce emissions and alleviate capacity shortages, especially the widespread implementation of respective innovative technologies in the air transport sector as envisaged by Destination 2050 (NLR & SEO, 2021), Flightpath 2050 (European Commission, 2011), EU Smart and Sustainable Mobility Strategy (European Commission, 2020), for example, and other studies (ACARE, 2017; Boeing, 2021; EREA, 2021; ERRAC, 2014; EUROCONTROL, 2018; Leipold et al., 2021; Roland Berger & UIC, 2021; SESAR Joint Undertaking, 2020; Shift2Rail, 2020).

Within ***Scenario 4, Decentralized, remote and digital mobility***, a shift toward a more decentralised network is assumed. As forecast by the UN World Urbanization Prospects (United Nations, 2020), the trend in urbanisation is not proceeding as anticipated in Europe, but the population has become more dispersed across rural and remote regions. These regions are becoming much more attractive due to enhanced options for remote working and virtual meetings. In line with the EU Smart and Sustainable Mobility Strategy (European Commission, 2020), remote and rural regions will be better connected to the European transport network. This implies a significant increase in small and regional airports and additional railway stations in the network, moving towards a more decentralised (air) transport network structure. This is accompanied by the widespread implementation of technological innovations for regional aircraft (ACARE, 2017; CER, 2020; EREA, 2021; ERRAC, 2014; European Commission; European Commission, 2011; European Commission, 2020; Leipold et al., 2021; Roland Berger & UIC, 2021; Schmalz, Paul, & Gissibl, 2021; SESAR Joint Undertaking, 2020; Shift2Rail, 2020).

2.2. Parameter development across scenarios

A range of parameters is considered for each scenario to depict potential future development pathways of air and rail transport within Europe. The *Socio-economic* category includes factors influencing the demand for mobility within Europe. The *Environmental / political* category focuses on the extent of regulations that may shape the demand for, and supply of, future mobility solutions (depicted in Table 2). We assume that environmental regulations are strongest in Scenarios 2 and 3, with regulations in the former aimed at inducing a shift from air to rail in the short-haul segment. In Scenario 3, these are targeted at fostering and implementing emission reduction technologies on a large scale.

Within the category *Mobility network*, those parameters are included that describe the level of demand as well as the elements and connections of the European air and rail transport network. In Scenarios 2 and 4, an improvement in (railway) station accessibility from urban and rural areas is assumed. In the former, a stronger focus is placed on the development of existing hubs and large airports (long-haul traffic focus), with feeder rail connections to airports increasing, and a strong cooperation between air and railway sectors. This also facilitates an increase of airport catchment areas, including improved airport access. Inter-city and HSR connectivity on corresponding short-haul segments are significantly improved by a well-connected railway network and higher frequencies. Compared to this, in Scenario 4, a more decentralised air transport network emerges, integrating existing and new small and regional airports to increase the overall connectivity of urban and remote regions. Airport catchment areas, especially small and regional airports, increase due to improved accessibility from rural and remote regions.

Table 2. Socio-economic, environmental/ political development and Mobility network categories.

Scenario parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		Socio-economic category		
NUTS2 population	Aging and increasing | UN medium fertility variant			
NUTS2 GDP of departing and arriving airports/stations / NUTS2 average households' income	Current status	Moderate increase	Strong increase	Moderate increase
		Environmental and political development category		
Environmental regulations	Low increase	Strong increase	Strong increase	Moderate increase
		Mobility network category		
Air traffic demand (passengers per city pairs)	Current status	Decrease in growth in the short-haul market	Strong growth	Moderate growth
Rail traffic demand (average number of passengers)	Current status	Strong growth	Strong growth	Moderate growth
Assumed air space improvement	Current status	Weak improvement	Strong improvement	Moderate improvement
Assumed rail network improvement	Low level of improvement	High level of improvement	Moderate level of improvement	High level of improvement
City archetypes	Continuation of *status quo* structure (recovered to pre-pandemic)	Stronger focus on existing hubs and large airports (long-haul traffic focus) and feeder rail connections	Uniform growth across air and rail networks, with little or no differentiation between route or node types	Decentralised air transport network
Number of busy airports (airport traffic)	Current status	Current status	Increase	Increase in small and regional airports
Number of HSR lines	Small increase	Strong increase	Strong increase	Moderate increase
Airport catchment area effects	Small increase in airport catchment areas	Increase in airport catchment areas	Increased airport catchment areas	Airport catchment areas increase

In this work, some parameters are based on level 3 of the nomenclature of territorial units for statistics (NUTS3†). The city archetype parameter, for example, is based on a combination of air and rail transport mobility factors of NUTS3 regions. The building of joint *city* archetypes avoids being tied to specific constraints at a particular airport/ railway station and therefore allows us to consider the movements between two regions more holistically. The city archetypes classification is defined in Table 3.

Table 3. City archetype classification

City archetype level	Airport archetype	Railway connection to airport	Further railway info
1	Main hub	Good inter-regional, direct HSR to airport	-
2	Main hub	Good inter-regional, no direct HSR to airport	HSR connected to the city only
3	Secondary hub	Good inter-regional, no direct HSR to airport	HRS connected to the region only and/or good mainline rail
4	Large/Medium	Good inter-regional, no direct HSR to airport	
5	National/regional	Near good inter-regional/ No HSR	

The classification of the NUTS3 regions based on the city archetypes allows us to consider future air/rail expansions. Therefore, in line with the various scenarios, different levels of promotion/demotion will be applied to

† NUTS is a hierarchical system for dividing up the economic territory of the EU and the UK for the purpose of development of European regional statistics, socio economic analysis of regions, and policy framing of European regions (Eurostat, 2020). NUTS level 3 (NUTS 3) refers to the small regions with the approximate population of 150,000 to 800,000.

the list of airports. Under promotion, airports that are classified as archetype 3, for example, will be considered along with any future airport expansion and/or HSR connectivity plans to such airports, or the regions in which they are located. Under demotion, the list of airports classified as e.g. archetype 3 will be considered in contexts such as those whereby services (e.g. short-haul operations) may be reduced, and such airports could thus be demoted to city archetype 4 under the modelling of Scenarios 2 or 4. A degree of stochasticity will be applied to the promotion/demotion rules to reflect longer-term planning and development uncertainty. Therefore, by designing a promotion/demotion approach and having access to the right data regarding air and rail expansion plans, under different scenarios, the level of city archetype can be meaningfully changed in either direction (promotion/demotion).

Table 4. Transport supply and technological development category.

Scenario parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Rail transport frequency	Low increase	Strong increase	Strong increase	Moderate increase
Air transport frequency	Low increase	Decrease in short-haul frequencies	Strong increase	Moderate increase
Rail supplied capacity (maximum number of carried passengers)	Low increase	Strong increase	Strong increase	Moderate increase
Air supplied capacity (maximum number of carried passengers)	Low increase	Decrease in short-haul traffic	Strong increase	Moderate increase
Type of train used	More HSR trains are employed, focus on specific high-demand routes	The use of HSR services and trains increases significantly	The use of HSR services and trains increases significantly	More HSR trains are employed
Travel time (air or rail segment)	Current status	Reduced travel times in both the air and rail sector	Current status	Reduced travel time in the air transport sector
Share of train leaving (or arriving) on time	Current status	Strong increase	Moderate increase	Moderate increase
Share of aircraft leaving (or arriving) on time	Current status	Increase	Decrease	Moderate increase
Monthly price index for rail transport	Current status	Weak increase	Moderate increase	Moderate increase
Monthly price index for air transport	Current status	Strong increase	Moderate increase	Moderate increase
Level of air-rail integration and cooperation	Low degree	High degree	Medium/low degree	High degree
Implementation degree of new aviation technologies	Current status	Moderate degree	High degree	Moderate degree
Implementation degree of new rail technologies	Current status	High degree	Moderate degree	Moderate degree

Transport supply (Table 4) describes those parameters determining the quality and quantity of supplied transport. The main differences between the scenarios are the supplied capacities, in terms of frequencies. In Scenario 2, compared to the pre-pandemic scenario, the rail sector experiences a substantial increase in these supplied capacities, whereas the air transport sector is subject to a decrease in the short-haul segment. Due to incentives and regulation fostering the rail sector, including investment and implementation of related technologies, rail-related travel times are reduced due to the improved railway network and the increase in supplied capacities. In this context, a strong focus is also placed on expanding and improving air-rail feeder connections to large hub airports. In Scenarios 3 and 4, both sectors see a strong and moderate increase in capacity, respectively. In Scenario 3, both sectors experience a widespread uptake of innovative technological solutions, thus allowing for a significant reduction in emissions and the accommodation of increasing mobility demand. In Scenario 4, air and rail network change is towards decentralisation, leading to reduced travel times across well-established rural and remote connections. In line with this, regional air transport, facilitated by implementing emissions reduction technologies, gains importance.

Across the four scenarios, these parameters exhibit different development pathways, e.g. increasing or decreasing, to set up plausible and potential air and rail transport demand and supply direction. This enables a differentiated discussion and baseline for policy recommendations and investment options for both sectors. A key challenge for the project is the parameterisation of Table 4 across the scenarios in the simulation model.

3. Discussion

These potential development pathways of the European mobility sector are not mutually exclusive, different regions may exhibit certain features of multiple scenarios, for example. The various assumptions and changes introduced across these scenarios may have significant implications for multiple transportation system elements.

3.1. Anticipated impacts across scenarios

Firstly, ***reducing emissions*** from the transport sector in Europe is one of the major goals different modes are pursuing. A measure discussed in this context is a shift from air traffic to the rail sector, especially in the short-haul market, as also addressed in Scenario 2. So far, studies indicate that the shift from air to rail could lead to a potential reduction of total EU aviation CO_2 emissions within the range of 2 to 4% for flights up to 1,000 kilometers (Transport&Environment, 2022), or of 1 to 2% for banning all flights up to 500 kilometres (Oxera, 2022). The assessment of a modal shift in general, and more specifically on designated city pairs or connections, has to take into account additional factors, including the number of eligible routes on which rail serves as a feasible alternative in terms of e.g., travel times, available railway capacities to accommodate the passenger shift, the environmental impact resulting from building new railway tracks and providing additional capacity, and the lifecycle costs of operating both aircraft and trains (European Environment Agency, 2020; Oxera, 2022; Transport&Environment, 2022). Oxera (2022) outlines that a shift from air to rail on short-haul connections also has to consider the potential network effects regarding airline feeder flights to hub airports, as also addressed by experts in the Modus workshop (Modus project, 2022). Replacing feeder flights by rail connections may lead to significant disadvantages for passengers in terms of travel times and ticket prices. Other airlines offering flights via hub airports outside of Europe may benefit, leading to carbon leakage, i.e. emissions are shifted, and negative competition effects for European airlines may arise.

Secondly, ***passengers' overall journey times***, especially considering the door-to-door dimension, are another essential aspect of multimodal mobility in Europe. Travel time, next to price, is one of the most critical decision-making factors for travellers when it comes to modal choice (Modus project, 2021). Greenpeace e.V. (2021) found that 51 of the 150 most important flight routes within Europe (in terms of passenger numbers) can alternatively be made by rail within up to six hours or less; however, this is not considering potentially available capacities. With rail journey times exceeding air travel times significantly, which is often the case for distances longer than 1,000 kilometers, air-rail substitution is considered less attractive by travellers. Avogadro et al. (2021) assessed the travel time and regional accessibility impact of route substitutability between air and rail, and found that 7.2% of intra-European flights could be replaced with a suitable alternative, with a maximum increase in travel time of 20%. This includes different types of passengers, not just those traveling on direct connections but also transfer passengers. The authors highlight that replacing these routes could reduce respective CO_2 emissions by up to 4.72%. Furthermore, the paper concludes that a shift from air to rail on short-haul routes would have a higher impact on central areas than peripheral ones in terms of decreased accessibility.

Technological advancements in both the rail and the aviation sectors are considered a means to reduce emissions significantly. The technological scenarios in the ATAG (2021) study outline various potential efficiency improvements by technological innovations for aircraft, for example. This includes the widespread implementation of electric, hybrid and zero-emissions aircraft within the time horizon of 2040 (see also NLR & SEO, 2021). In the rail sector, a reduction in energy consumption, efficiency improvements, and hence emissions reduction are also envisaged. The focus is placed on additional electrification or low-carbon propulsion technologies (CER, 2020). The rail sector has been also working on multimodal and cross-border enablers, creating the specifications for train ticket sales that harmonise the different ways of selling tickets (OSDM2), Europe-wide integrated rail timetables (MERITS3), and the basis for full ticket digitalisation (ETCD4) in the context of a ticketing roadmap. (CER, 2021)

As one of the main goals of the European mobility strategy, enhancing the ***connectivity of remote and rural regions*** is within the focus of Scenario 4. Connectivity can be improved by a better air and rail transport network to these regions, thus reducing travel times and offering inclusive mobility offers. For example, Grimme, Paul, Maertens, & van Wensveen (2020) illustrate the potential advantages of a 19-seater hybrid-electric aircraft for the German market, including travel time savings.

3.2. Expert insights on scenarios

In addition to these possible impacts, industry experts from the air and rail sector provided their inputs regarding the proposed scenarios in a participatory workshop in February 2022 (Modus project, 2022) to discuss implications for the entire mobility system and its transport service providers, and to identify further research needs. Points raised for scenario improvement included a continuous revision and update of such scenarios, as well as the integration of novel transport modes and required infrastructure, such as urban air mobility (UAM), vertiports, bus services, and ride-hailing. Furthermore, experts outlined that the scenarios should become more passenger-centric. For this purpose, passengers could be consulted about their future transport needs (e.g., their value of time, how much personal data they are willing to provide) and how to enhance their travel experience. Such consultation via passenger associations and representative groups inputs is invaluable, whereas direct surveys are out of the budgetary scope for Modus. More widely, this could imply going beyond using only personas but considering (real-time) data as crucial, how these data could be (better) accessed, and how providers could be motivated to share their data in an intermodal manner. Other areas to be considered include regulatory frameworks for emissions reductions, data protection, and improving telecommunications as a shared infrastructure. For example, the General Data Protection Regulation (GDPR) has to be accommodated within a multimodal smart contract, e.g., protecting passengers' data. Clear regulations, such as end-to-end travellers' protection in case of disruption, on a European level, are currently lacking – legal accountability remains a challenge

The experts considered the scenarios to be not mutually exclusive, with different aspects of all four scenarios potentially appearing across Europe. Air-rail cooperation and some degree of the shift from air to rail are already apparent in some parts of Europe, as outlined in Scenario 2. Regarding Scenario 4, rail and ATM could be integrated through intelligent tools to become a customer interface, such as factoring in demand data from key origins and destinations (e.g., schools, hospitals). Various barriers have to be overcome first, including the facilitated exchange between service providers, long infrastructure development projects, investment challenges and market entry barriers. Lastly, a scenario with a long-term decrease in travel demand is missing, which could be triggered by the global Covid-19 pandemic, decreased globalisation, or a stronger buy-local mentality.

4. Conclusion

The challenges the European transport system and its participants face are manifold, but many are urgent. Developing and assessing scenarios for potential development pathways are valuable tools for strategic decision- and policymaking. The approach within this paper shows that, across all scenarios, the emissions reduction potential, in light of a full lifecycle cost and environmental impact assessment, as well as the impact on door-to-door travel times, has to be considered when improving multimodal cooperation or substitution across Europe. Furthermore, strengthening multimodality in Europe means ensuring the connectivity of regions, a holistic assessment of investment in modal alternatives, enabling cross-border tickets, and implementing a common regulatory framework that addresses passenger rights, data sharing, and the concept of single ticketing.

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