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SESAR JOINT UNDERTAKING

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Modus

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

This deliverable is part of a project that has received funding from the SESAR3 Joint Undertaking under grant agreement no. 891166 under European Union's Horizon 2020 research and innovation programme.

Abstract

The Final Project Results Report of the Modus project provides a comprehensive overview of the project. First, it outlines the operational context, the project scope and the objectives in order to show the relevance of the project to the ATM Master Plan as well as other European high-level strategic mobility agendas. Based on this scope and the objectives, the report describes the work performed and discusses the key project results, including a list of all technical deliverables. Based on the work performed and the results, the report contains a detailed maturity gate assessment which described the Modus solution and how this solution has been achieved. Furthermore, the report describes the overall conclusions of the project, the technical lessons learned and identifies further R&D needs.

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1 Executive Summary

The topics of multimodality, passenger experience and inclusion as well as creating a seamless mobility system within Europe that meets the goals of the Paris Climate Agreement, are high on the agenda of shaping the future European transport system. The Modus project focused on modelling and assessing the role of air transport in an integrated, multimodal transport system, with a focus on joint air-rail mobility. This approach helps in gaining an enhanced understanding of multimodal traveller requirements, air-rail modal choice decisions and advancing and implementing models to better depict passengers' door-to-door journeys, and to do so across different future mobility scenarios.

As a key result, a modelling approach for the assessment of seamless door-to-door multimodality and the passenger experience in Europe has been developed. It was applied to evaluate the impact of an improved, joint air-rail transport system, characterising the contribution of air traffic management (ATM) and air transport to the improvement of travellers' multimodal journeys. This has been done across four different future scenarios that depict potential development pathways of air-rail mobility in Europe, including a significant short-haul shift from air to rail, traffic growth with strong technological support, or a move towards a more decentralised, remote and digital mobility.

The Modus modelling approach can be used to assess the resulting impacts on capacities, predictability, and the environment, across these scenarios and for multimodal journeys. This can provide useful support for policy makers as well as transport service providers in shaping future multimodal mobility.

A truly multimodal mobility system has to meet certain requirements, inter alia:

- Close cooperation between air and rail mobility providers to ensure a seamless door-to-door journey for travellers (including data availability and sharing, integration of privacy requirements).
- Holistic approach to meet the climate goals and comprehensive assessment of different modes.
- Integration of remote regions, their connectivity and accessibility, and taking into account diverse traveller needs.
- Emergence of new actors in the mobility market as well as business models.
- Setup of a regulatory framework for better cooperation.

Moving towards true multimodality, the following enablers have to be considered:

- Legislation and a regulatory framework are required that foster cooperation across modes and across national borders.
- Design of measures, policies and incentives which are tailored to specific regions and routes.
- Transparency of all and external costs of transport modes in order for policy makers and travellers to make informed decisions.

- Establishing smart travel includes data availability and sharing, the avoidance of disruptions, and/or the dynamic rescheduling of journeys.

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2 Project Overview

2.1 Operational Context, Project Scope and Objectives

In the context of increasing environmental awareness, regulatory measures, capacity shortages across different modes, and 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 optimisation 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.

When envisaging this future multimodal European transport system, many challenges come to one's mind which need to be addressed and realised to improve passenger journey's and the overall travel experience:

- Enabling a seamless passenger journey, including multiple providers and information.
- Meeting environmental goals and facilitating a sustainable transport system.
- Identifying and developing new business models that enable multimodal transport.
- Tackling the long-term implications resulting from Covid-19.
- Rethinking the use of current infrastructure and future challenges.

The topics of multimodality, passenger experience and inclusion as well as creating a seamless mobility system within Europe that meets the goals of the Paris Climate Agreement, are high on the agenda of shaping the future European transport system. Different mobility and aviation strategies outline respective objectives accordingly.

The European Commission set up the Sustainable and Smart Mobility Strategy in 2020 [1] incorporating a multitude of goals and respective flagships that pave the way towards zero-emission, resilient and inclusive mobility, creating seamless and efficient connectivity, and establishing the European Union as a connectivity hub. In terms of sustainable mobility, one of the goals is a stronger focus on multimodality. This is encompassed in the objectives that "sustainable alternatives must be made widely available now in a fully integrated and seamless multimodal mobility system" (p. 7), and that "Europe should build a high quality transport network with high-speed rail services on short-haul distances and with clean aviation services improving coverage of long-haul routes" (p. 7). One of the pillars enabling smart and seamless mobility is "EU-wide, integrated, multimodal information, ticketing and payment services" (p. 12). Furthermore, in order to "create a truly smart transport system, efficient capacity allocation and traffic management must also be addressed to avoid a capacity crunch and reduce CO_2 emissions" (p. 13). The strategy also comprises that "mobility [is] affordable and accessible in all regions and for all passengers including those with disabilities and reduced mobility" (p. 17), and that a "multimodal framework for passenger rights [is pursued] that is simplified, more consistent and harmonised" (p. 17).

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Succeeding the European Flightpath 2050 [2], the new aviation vision Fly the Green Deal [3] sets out the strategy for aviation up to 2050. Multimodal transport also plays an essential role in aviation's strategic objectives. Airports are envisaged to become multimodal connectivity hubs that facilitate seamless transfer between modes. In addition to this, the vision states that a "legal framework for seamless door-to-door journeys [needs to be] in place addressing passenger rights in a multimodal transport environment as well as enabling personalised travel and reconfiguration of journeys by exchange of contextual journey information in a GDPR-compliant way" (p. 58). In line with these objectives, the ACARE SRIA [4] highlights the focus on a customer-centric transport system, the design and implementation of an integrated, intermodal transport system, and emphasises that it is important to develop capabilities to evaluate mobility concepts, infrastructure and performance.

The European Air Traffic Management (ATM) Master Plan (MP) [reference] outlines multiple goals and performance ambitions for this sector, including the accommodation of additional air traffic growth and the reduction of emissions of aviation. Furthermore, in terms of operations, multimodal mobility is emphasised to contribute to "a safe, efficient and green travel experience and promote use of the most appropriate means of transport" (p.76). In this context, the Master Plan also highlights the need for a multimodal regulatory framework in order to connect multiple modes and to achieve door-to-door mobility. The SRIA Digital European Sky [4] complements the MP and details the roadmaps to achieve this. Two of the flagships areas are multimodality and passenger experience. Here, aspects such as seamless travel but also predictability of door-to-door journeys are emphasised as needs and challenges, and the role ATM plays in terms of punctuality of flights and capacity allocation in the system, for example. Creating a seamless passenger experience and interoperability between different transport providers will be enabled by "[the] complete integration of airports as multimodal nodes into the ATM network" and hence contributes to "increasing network resilience and the reliability and predictability of journey parameters, enhancing punctuality and passenger experience overall" (p. 57). Furthermore, placing increased focus on multimodal solutions will facilitate "additional environmental benefits […] from alleviating congestion at and around airports by improving passenger flows (through predictability and single-ticketing), from helping access/egress to/from airports, using environmentally-friendly means […]" (p. 57).

In line with these, the Modus project focused on modelling and assessing the role of air transport in an integrated, multimodal transport system, with a focus on joint air-rail mobility. In particular, a modelling approach for the assessment of seamless, door-to-door multimodality and the passenger experience in Europe has been developed. It was applied to evaluate the impact of an improved, joint air-rail transport system, characterising the contribution of air traffic management (ATM) and air transport to the improvement of travellers' multimodal journeys. Specifically, the scope of the project and respective objectives have been as follows.

(1) <u>Multimodal door-to-door mobility</u>: Understanding the potential contribution of ATM and air transport to improve passengers' intermodal journeys and how this translates into an enhanced performance of the overall transport system, including

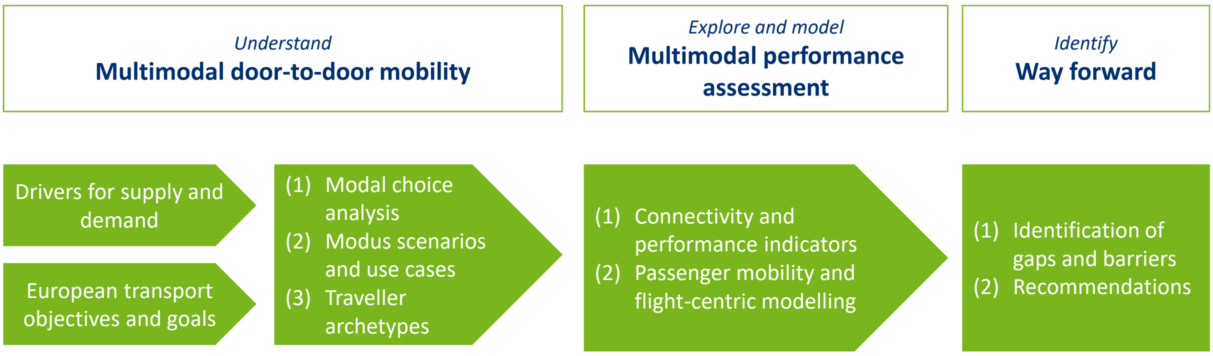
- identifying and assessing (future) drivers for traveller demand and supply of mobility, and how these affect passenger mode choice, and
- the development of scenarios and passenger archetypes that depict various potential future development paths which the European transport system might be facing.

(2) Multimodal performance assessment: 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, with

- an integrated modelling approach which includes the development of data-driven models of air and ground passenger transport in Europe, together with a passenger modal choice intended to capture the outcomes of different passengers' behaviour, and their effect across multimodal scenarios in Europe, and

- the consideration of passenger mobility metrics that enable quantitative insights into the performance of the European transport network.

(3) Way forward: 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.



The project deployed passengers' modal choice decisions based on a combination of airport and railway station connectivities, city archetypes and respective catchment areas. This enabled door-to-door journey modelling for a variety of traveller types, using the modal choice modelling output to adjust individual traveller itineraries in the air-rail network. As a further contribution, the solution considered various future scenarios that depict different potential development pathways of air-rail mobility in Europe, including a significant short-haul shift from air to rail, traffic growth with strong technological support, or a move towards a more decentralised, remote and digital mobility.

The Modus modelling approach can be used to assess the resulting impacts on capacities, predictability, and the environment, across these scenarios and for multimodal journeys. This can provide useful support for policy makers as well as transport service providers in shaping future multimodal mobility. In particular, benefits for different mobility stakeholders include:

- To better understand and assess the impact of air and rail as substitutes and complements.

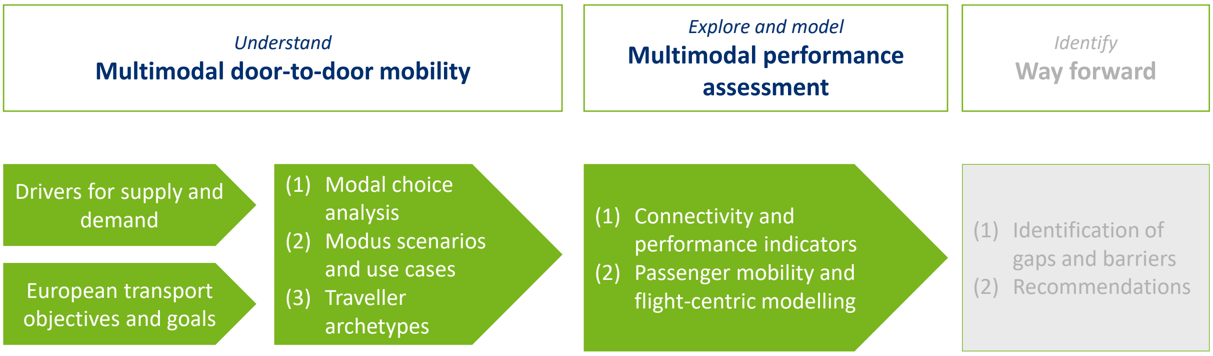
- To gain a detailed picture of diverse traveller profiles and their requirements throughout the door-to-door journey.

- With the help of Modus scenarios, to obtain insights into possible future development paths of European mobility.

The Modus approach and how this meets the objectives are outlined in Section 2.2. Based on this, Section 2.3 outlines and discusses the key project results, reflected in the technical deliverables outlined in Section 2.4. Section 3 provides the links to the SESAR programme, both in terms of Modus' contribution to the ATM Master Plan and the project's maturity assessment. Section 4 outlines the conclusions, lessons learned and next steps for further research.

2.2 Work Performed

This section describes the work performed in the course of the Modus project, the results are presented in Section 2.3.



2.2.1 Multimodal door-to-door mobility

Within the first pillar of the Modus project, the focus has been placed on understanding in a better way how multimodal journeys of travellers can be improved, and which factors affect modal decision making along different future development paths of the European transport system.

First, those drivers were identified and analysed which have an impact on the supply of and demand for future air-rail mobility solutions. These drivers as well as relevant European high-level mobility objectives provided the basis for the establishment of four multimodal scenarios and different use cases that describe particular elements of a passenger journey from door to door. Further, a subset of these factors has been integrated into a modal choice analysis to assess market shares for air and rail in Germany, France and Spain, and to identify price elasticities for these markets. In order to understand and assess future multimodal door-to-door journeys, the passenger perspective is of high importance. Since perspectives, requirements and resulting travel behaviour can differ, seven distinct traveller archetypes have been developed within the Modus project.

Drivers of future mobility supply and demand

The identified future drivers of supply and demand were applied both in the development of scenarios as well as the modal choice analysis (see Modus Deliverable D3.1). The approach was threefold and included (1) a detailed literature review, (2) an expert survey and (3) a multimodality workshop, the latter both involving experts from different transport sectors, especially air and rail (January 2021). The identified drivers were clustered into different categories, including social, technological, economic, environmental, and political or mobility factors.

The expert survey complemented the comprehensive picture of supply and demand drivers of air and rail transport. Among all the considered drivers, economic and gross domestic product (GDP) change (e.g., economy is growing, GDP levels are increasing) and intermodal integration and Mobility as a Service (MaaS) were recognised by the experts in the survey as the two major factors playing a significant role in supply and demand aspects. In addition, increasing passenger environmental attitudes and environment-related regulation are expected to boost rail supply and demand further.

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.

This first Modus multimodality workshop also 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 essential. 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.

A selection of these factors has been parametrised and integrated in both the scenario development and modal choice analysis.

Future multimodal mobility scenarios

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 briefly outlined below and described in more detail in Modus Deliverable D3.2. In line with European high-level mobility objectives, particular emphasis was placed on connectivity, the environmental impact of mobility, the integration of additional demand, and technological innovation and its (widespread) implementation.

Scenario 1: Pre-pandemic recovery (baseline)

- Network structures remain similar to todays
- Implementation of innovative technologies facilitates the reduction of emissions in air transport

Scenario 2: European short-haul shift

- High share of short-haul air traffic replaced by air-rail cooperation
- High quality of transport network with HSR services on short-haul distances

Scenario 3: Growth with strong technological support

- Higher growth rates of the transport sector until 2040 than the baseline
- Uptake of technological innovations to both reduce emissions and alleviate capacity shortages in air transport

Scenario 4: Decentralized, remote and digital mobility

- Population becomes more dispersed across rural and remote regions with increased options for remote working and virtual meetings
- More decentralized air transport network, additional railway stations
- Technological innovations for regional aircraft

Figure 1: Modus future supply and demand mobility scenarios

Industry experts from the air and rail sector provided their inputs regarding the proposed scenarios in a second, participatory Modus workshop in February 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

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as the integration of novel transport modes and required infrastructure, such as urban air mobility (UAM), bus services, or 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 have been out of the budgetary scope for Modus. More widely, this could imply going beyond using 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 personal data of travellers. Clear regulations, such as end-to-end travellers' protection in case of disruption, on a European level, are currently lacking. Further, 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. 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 ongoing, global Covid-19 pandemic, decreased globalisation, towards a stronger 'buy-local' mentality.

These scenarios are investigated in both the modal choice analysis as well as the passenger mobility modelling (see results in Section 2.3).

Use cases

The Modus use cases reflect objectives of high-level European mobility strategies as well as factors identified within the Modus project that are essential for the establishment of a multimodal European transport system, with a particular emphasis on the relationship between air and rail. As a first step, relevant mobility strategies and goals towards an integrated, intermodal transport sector were reviewed and high-level topic areas identified, including *Ticketing, Interoperability and Data*, *Connectivity, Intermodal alignment and Environmental impact*. A detailed overview and description of the Modus use cases can be found in Deliverable D5.1.

Based on these topic areas, four Modus use cases have been defined, which represent particular aspects of the identified topic areas and which are considered as having a significant impact on mobility processes, capacities and/ or journey times, for example.

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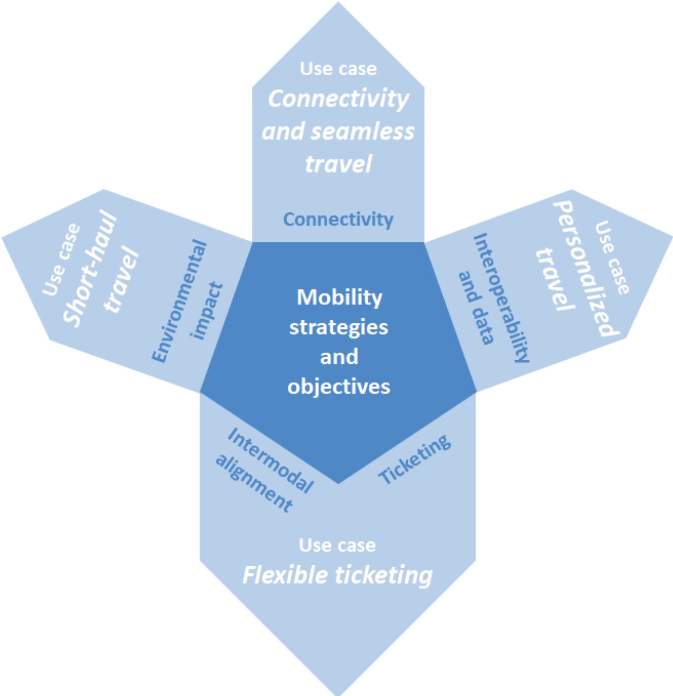


Figure 2: Mobility objectives and Modus use cases

These represent key aspects of the door-to-door journey in Europe, ranging from the analysis and discussion of the impact of *Flexible ticketing* on re-accommodating passengers in case of disruptions, to the potential policy-incentivised replacement of *Short-haul travel* on selected routes within Europe. In addition to this, the role of *Connectivity and seamless travel* is considered to be essential as well as the degree of *Personalised travel*, hence constituting the remaining two use cases.

The specification of the use cases enables a detailed discussion with experts from various transport domains as to how these use cases enable an integrated, multimodal transport system, and to assess the impact on available capacities or travel times across the different Modus scenarios (see Section 2.3.4).

Modal choice

The modal choice analysis applied in Modus provides insights into an individual's choice to travel on a specific route (origin-destination pair). The relevant market is the geographic area where a customer can select a rail station or airport for the departure and origin. We assume, for instance, that two airports or rail station in neighbouring cities could be alternatively chosen by a customer for their departure or arrival. Therefore, these airports or rail stations belong to the same set of possibilities, and customers' travel choice is modelled in a two-stage decision process. The underlying assumption is the existence of an oligopoly structure where different providers of transport services supply differentiated products. These firms compete both in price and quality of services. We restrict our analysis to **price competition** assuming that product characteristics are fixed ex ante. The customer chooses the alternative which maximises their level of utility. We assume that each customer decides first the mode of transport among train, plane and car. Then, given this choice, an alternative according to its characteristics is selected: price of the ticket, carrier, and quality of service, day and time of travel, among others. The model allows measuring intra and intermodal competition: competition between alternatives within a mode and competition between modes respectively. We focus our analysis on routes where the two modes of transport, train and plane, are supplied by at least one service provider. We assume that passengers can choose to travel by car, whatever the route under consideration. Car is therefore considered as an outside good and plays no strategic role in the competition between plane and train.

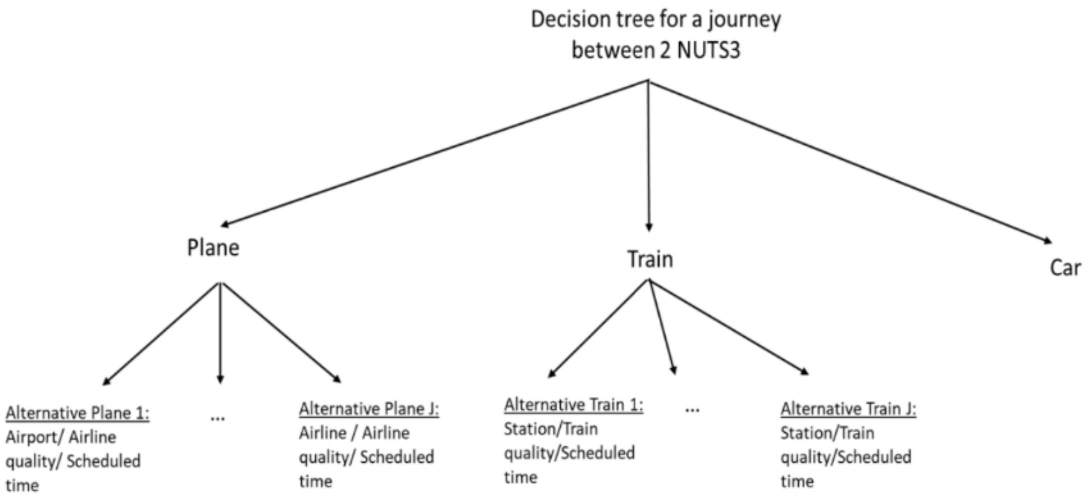


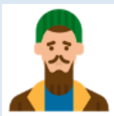
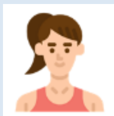
Figure 3: Decision tree for a journey between two NUTS3

We have chosen to consider the intra and intermodal competition at a NUTS-3 level. We then consider as origin-destinations (ODs) in our model, all the combinations of two NUTS-3 regions where both air and rail operators propose direct trains or flights respectively (non-direct air or rail supplies are excluded from our analysis.

The data collection is described in the Appendix and in Deliverable D2.1 (Data Management Plan), the results of the modal choice analysis are discussed in Section 2.3.1.

Traveller archetypes

For the purpose of the Modus project, future traveller archetypes from the CAMERA project have been adapted [1]. In total, seven future, long-distance traveller archetypes were developed (Deliverable D3.2). Each passenger archetype exhibits distinctive characteristics which were translated into according parameters for the different components in the landside model. This approach is described in more detail in Modus Deliverable D4.1.

Characteristics (partly based on drivers identified in D3.1)	**1) Business Flyer** 	**2) Digital Gen Z Flyer** 	**3) Environment-minded Flyer** 	**4) Premium Flyer** 	**5) Cultural Jetsetter** 	**6) Holidayer** 	**7) Golden Senior Flyer** 
Main motive of travel	business	mainly private	private & business	mainly private	mainly private	mainly private	private

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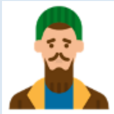
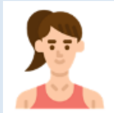
Characteristics (partly based on drivers identified in D3.1)	1) Business Flyer 	2) Digital Gen Z Flyer 	3) Environment-minded Flyer 	4) Premium Flyer 	5) Cultural Jetsetter 	6) Holidayer 	7) Golden Senior Flyer 
Frequency of travel	frequently / very frequently	occasionally	occasionally	occasionally to frequently	occasionally to frequently	occasionally	frequently
Travel party size	1 to 2	1 to 2	1 to 2	up to 5 persons (family size)	1 to 2	single and up to 5 persons (family size)	1 to 2 (could also travel as part of organised travel group)
Burden (travelling with dependent people)	no	no	no	travelling with kids	no	travelling with kids	travelling with impaired companion
Booking/ Information gathering	online, travel agency (high-yield traveller)	online (high-yield traveller)	online (inflexible booking options)	in-person, travel agency (high-yield traveller)	online (inflexible booking options)	online (inflexible booking options)	in-person, travel agency (high-yield traveller)
Individual characteristics of users (criteria that define an individual)							
Predominant age group	18 - 65	15 - 70	15+	18+	15 - 65	30+ (with children under 15)	60+
Occupation	business or job-nomad (project work)	student, business, knowledge worker	student, business	business	student, business, knowledge worker	from low profile job to business	mostly retired
Category of salary / income	medium / high	high	medium	high	low / medium / high (more medium / high)	low / medium	medium
Price elasticity	low (premium)	low (premium)	medium (premium /economy)	low (premium)	medium / high (premium)	medium / low (economy)	medium (premium / economy)
Household size	not relevant	1+	1+	from solo-traveller up to 5 persons (family size)	1+	from solo-traveller up to 5 persons (family size)	1 to 2
Psychological and sociological representations (travel needs that help to understand how profiles archetypes transport)							

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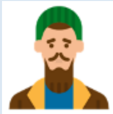
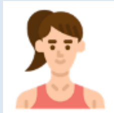
Characteristics (partly based on drivers identified in D3.1)	1) Business Flyer 	2) Digital Gen Z Flyer 	3) Environment-minded Flyer 	4) Premium Flyer 	5) Cultural Jetsetter 	6) Holidayer 	7) Golden Senior Flyer 
Expected level of comfort	high	high	low	medium to high (premium)	medium	medium / high	medium
Degree of personalisation	high	high	high	high	low to medium	low	high
Technological affinity	high	high	low / medium	medium	high	medium	medium
Value of time	high	high	medium	medium	high	low	low
Further characteristics / requirements and values							
	working during travel	high digitalisation; environmental conscious	environmental conscious and act accordingly	high space requirements	travel as experience; environmental conscious	high space requirements	might need assistance

2.2.2 Multimodal performance assessment

2.2.2.1 Multimodal connectivity and performance indicators

A better understanding of the performance of the European multimodal transport system can help to design better policies, invest in capacity and infrastructure or enhance passengers' door-to-door journeys. Finding those indicators that represent elements of a multimodal door-to-door journey as well as potential impacts for different stakeholders has been one part of the Modus project. In regard to the key performance indicators (KPIs) identified as relevant for Modus, several key issues need to be flagged, to which careful attention has been paid by the project:

1. avoiding a proliferation of KPIs in the reporting;
2. identifying headline KPIs;
3. adopting some degree of complementarity with other SESAR ER work (notably the TRANSIT project (https://www.transit-h2020.eu/);
4. avoiding inadvertently 'trivial' relationships with model assumptions, such comparisons being useful for calibration and validation.

Within Deliverable D3.2, we have presented a wealth of indicators, many of which are already incorporated into the Mercury model, which underpins the scenario simulations analysis in Modus. We have noted that many of these indicators (in Mercury) currently correspond to the air transport and ATM contexts (although they also include airport access and egress times), such that in the development of the Mercury model these indicators, need to be extended to the rail context. As a finding from the analysis of numerous key performance indicators in Modus, some of these, where we focused on the intermodal context, can be seen as 'cooperative' in nature, i.e. measuring specific outcomes (e.g. D2D reach) that will be improved through air-rail cooperation, and be driven through assumptions in the scenarios (e.g. particularly regarding short-haul bans).

2.2.2.2 Introduction to the mobility models

Re-cap on the Mercury and R-NEST mobility models

As described in Deliverable 4.2 (Mobility models description, there are four main Modus future scenarios, which are derived from high-level mobility objectives, existing scenario studies, and the work conducted within the Modus project. Scenarios 1-3 are, furthermore, modelled in Mercury and R-NET, as described below. The main features captured in the scenarios are:

- **Scenario 1, pre-pandemic recovery**, is a future 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.

- **Scenario 2, European short-haul ban**, envisions that the 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. As a threshold, we have selected 500km (measured as the great circle distance between cities) as the maximum distance for a flight to be replaced by rail. Furthermore, we have identified four countries (Spain, Italy, France and Germany) to limit the study, given the development of their HSR network.

- **Scenario 3, growth with strong technological support**, high growth rates in the transport sector until 2040 are assumed, which significantly exceed those in the baseline scenario.

Deliverable 4.2 also set out the main elements of the two simulation models used by Modus: the Mercury passenger mobility model and the EUROCONTROL R-NEST tool. Whilst these mobility models are run separately, commonalities to support the inclusion of a rail layer in both models, and for each to model the full door-to-door context of passenger multimodal journeys, were presented in D4.2. Both models (Mercury, R-NEST) originated as air traffic simulators, and are being extended to take into account the possibility of rail travel and other components of the trips that are needed to calculate door-to-door metrics.

The holistic approach in Modus, integrating air and rail in the wider, door-to-door context, prompted the development of city archetypes, rather than focusing on airports or railway stations per se. A city archetype denotes a specific combination of airport and railway connections and allows us to generalise the modelling based on the construction of typical urban travel infrastructure. This impacts the modelling at two levels. Firstly, it allows, holistically, the consideration of movements between ‘Paris’ and ‘London’ and the future of such flows, rather than being tied to specific constraints at particular airports, for example. Secondly, it allows the construction of urban mobility models relating, for example, to airport and railway station access and egress, with generic travel time distributions per archetype. Various stages of the air passenger journey are defined, viz.,: door-to-kerb (D2K); kerb-to-gate (K2G); gate-to-gate (G2G); gate-to-kerb (G2K); kerb-to-door (K2D). Corresponding stages were defined for rail passengers, viz., door-to-platform (D2P), platform-to-platform (P2P) and platform-to-door (P2D), in addition to a set for multimodal journeys: gate-to-platform (G2P); platform-to-gate

(P2G); kerb-to-platform (K2P), platform-to-kerb (P2K). The five city archetypes and associated travel time distributions were presented in Deliverable D4.2, as were the various airport process times, as a function of passenger archetype.

Modelling rail options in the two mobility models

(a) The Mercury rail options generator

In some of the Modus scenarios presented in this document, journeys originally planned by air are modelled in terms of the ability of the (high-speed) rail (HSR) network to accommodate them, or legs thereof, for example during bans on short-haul flights (scenario 2). Identifying routes with existing HSR and future construction planning of such services, is one of the main principles in assigning an appropriate archetype level to a particular city. This also supports the modelling of recovery under the disruptions applied. Routes which already have HSRs running and the ones with construction planning in place (HSR ready to run by 2040) were identified and listed in Deliverable D4.2.

In order to obtain the flows/itineraries for the short-haul ban models, we need to overlay air traffic flows with the rail network. The analysis performed by the rail options generator in the rail layer provides the different options available to passengers using rail. Rail can be used as a substitution of air travel or as a segment, i.e., in multimodal itineraries. All flights with a great circle distance lower than 500 km are considered as potentially replaceable by rail if the rail option (network links) exists. Demand flows which are only one-leg itineraries, i.e., only one flight, which overlap with a rail alternative, are considered as shifted to rail. For multi-leg itineraries, the rail mapping process identifies if the first or last leg can be performed by rail for a set of key hub airports identified as where multimodality can be performed (Madrid Barajas, Barcelona El Prat, Roma Fiumicino, Paris Charles de Gaulle, Paris Orly, Frankfurt, Munich, Berlin Brandenburg). Such segments are moved to rail. The model differentiates between railway stations in city centres and at airports, as the former requires the estimation of travelling time from platform-to-kerb. After this process, if for a given origin-destination all passenger demand has been shifted to rail, the supply, i.e., seats on flights, is also removed, i.e., the air link is fully moved to rail. Finally, note that this strategic use of rail is only considered for rail routes within Spain, France, Italy and Germany.

(b) The R-NEST treatment of rail options

A rail journey model is introduced in R-NEST, allowing the comparison of air and rail passengers' total travel times for the same city pairs. To allow the door-to-door rail travel time computation, average values based on observed public transport times in main European cities (e.g. Paris and Madrid), have been retained. The values corresponding to each rail journey's leg are:

- door-to-station and *vice versa*: 45 min;
- station-to-train: 30 min;
- train-to-station: 20 min.

The identification of the train stations, the type of train (normal or HSR) is based on EUROCONTROL's analysis of the MERITS data, as outlined in Deliverable D4.2, and referring to the work outlined in the preceding sub-section for Mercury. To evaluate the impact on high-speed rail (HSR), two mechanisms are introduced:

- short-haul ban: flights with a great circle distance lower than 500km are not operated by air in Germany, France, Spain and Italy, whereby a corresponding rail service exists to carry these passengers;

- extra rail competition: for all passengers, the total travel time is computed for both air and rail transport modes. Flight passengers will switch to the rail mode when a one-hour travel time benefit is observed for the rail mode compared to air. When 20% or more of an aircraft's passengers transfer to the rail mode, the airline will cease to operate the flight.

The 'short-haul ban' and the 'extra rail competition' strategies are applied to the both of the 2040 air demand forecasts (i.e. base and high scenario), resulting in a number of flights being transferred from air transport to rail.

2.3 Key Project Results

2.3.1 Modal choice analysis and introduction to the mobility models

2.3.1.1 Modal choice analysis

Table 1 presents the results of the estimation of the two stages modal choice decision model for the three analysed countries, France, Germany and Spain. All the parameters are statistically significant. The parameter Price is negative as expected, and σ (Ln sj/g) belongs to the interval [0, 1] as expected as well. This validates the specification of the model as a two-stages decision model. σ is high for Germany and Spain, meaning that intramodal competition is higher than intermodal competition in these countries. This high level of intramodal competition can be explained for Germany by a strong competition between high-speed trains and intercity trains on a large proportion of German routes. For Spain, conversely, there is a strong competition on the air transport market between full service and low cost carriers both operating on most of the considered routes. Such intramodal competition is lower in France where there are only one rail and one air operator on 42% of the studied French routes. The French market is therefore characterised by a stronger intermodal (air/ rail) competition.

Table 1: Model results per country

Variables	Model France	Model Germany	Model Spain
Price (Price Minimum for Spain)	-0.0443***	-0.0191***	-0.0561***
	(0.00392)	(0.000870)	(0.0101)
Ln(sj/g)	0.428***	0.936***	0.929***
	(0.0589)	(0.0160)	(0.0725)
GDP NUTS 3 departure (thousand)	0.00248	0.0539***	0.0316***
	(0.00641)	(0.00421)	(0.0112)
GDP NUTS 3 arrival (thousand)	0.00265	0.0591***	0.0327***
	(0.00602)	(0.00441)	(0.0106)
Attributes of alternatives	YES	YES	YES
Market fixed effect	YES	YES	YES
Carrier fixed effect	YES	YES	YES
Month fixed effect	YES	YES	YES
Observations	2,162	3,086	386
Model Statistics			
R-squared	0.841	0.947	0.973
F-Test	666.5	5437	1303
loglikelihood	-3281	-2908	-288.6
Tests of instrumental variables			
Kleibergen-Paap rk LM	128.9	272.7	73.68
p value	0	0	0
Cragg-Donald Wald F	228.6	442.4	99.21
Kleibergen-Paap rk Wald F	114	469.5	148.4
Hansen J	3.552	2.539	2.041
Chi-sq() P-val	0.0595	0.111	0.153
Endogeneity_test	216.8	441.5	41.46
Chi-sq() P-val	0	0	1.21e-10

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 2 presents the assessed own-price elasticity of demand per country. Demand in all countries is strongly sensitive to a change in the level of prices but this sensitivity is particularly high for Germany and Spain. For a 1% increase in the average level of fares, the average demand decreases by 5.3% in France, 9.1% in Germany and 10.8% in Spain.

Table 2: Own-price elasticities of demand per country

Country	Observations	Mean	Standard deviation
France	1,961	-5.34	1.59
Germany	2,582	-9.11	7.72
Spain	272	-10.78	9.74

This high level of sensitivity is observed both for air and for rail operators but is stronger for air operators whatever the country (see Table 3). The variability of price elasticities is high in particular for low cost carrier (LCC) services in Germany and Spain. The model provides very interesting information on the market structure sensitivity to changes in the level of fares. Even a small increase in the level of fares proposed by an operator may subsequently change the distribution of market shares between the competing operators on a route.

Table 3: Price elasticities of demand per mode, service quality and country

	France		Germany		Spain	
Country	**Major**	**LCC**	**Major**	**LCC**	**Major**	**LCC**
Plane	-6.03	-4.74	-6.11	-13.54	-17.58	-28.53
	(1.18)	(1.9)	(7.04)	(7)	(7.07)	(0.56)
Train	-5.21	-3.01	-4.62	-13.45	-1.54	-14.32
	(1.4)	(1.54)	(4.13)	(7.83)	(0.38)	(6.24)

This model allowed us to estimate the market shares of rail and air on several origin-destination routes for the scenarios depicted in Section 2.2.1. Although the model has not been designed to make forecasts, the integration of these scenarios is intended to show trends in the distribution of market shares, in our case for three different countries (France, Germany and Spain). For each country, several origin-destination markets have been analysed and the impact on rail and air market share compared to the 2016 baseline situation.

In **France**, the rail network represents a star-shaped pattern, and there are few rail transverse lines that do not pass through Paris. Moreover, very often the transverse lines between two cities other than Paris are classic lines. All the high-speed lines start or finish in Paris since it represents the centre of economic activity in France with a share of GDP of about 31% in 2016, and the centralisation of the country's administrative and economic activities. Although efforts to decentralise have been made since the 1980s, the railway network remains marked by this centralisation. The Lyon-Nantes markets is used as an example for the potential substitution between air and rail demand across two different scenarios, it is a so-called transverse origin-destination, meaning that it does not have Paris as its origin or destination. Nantes has one railway station that is not directly connected to the high-speed network and an airport that welcomed about 2.24 annual national passengers in 2016. By train, the Lyon-Nantes connection takes an average of 5 hours 32 and 4 hours 24 on the shortest connection. By plane, it takes 1 hour 15 and by car almost 7 hours.

In 2016, the market share of air transport accounts for 93%. For Scenarios 1 (baseline) and 2 (short-haul shift) it can be observed that the air transport market share is reduced by about three to four percentage points compared to the situation in 2016.

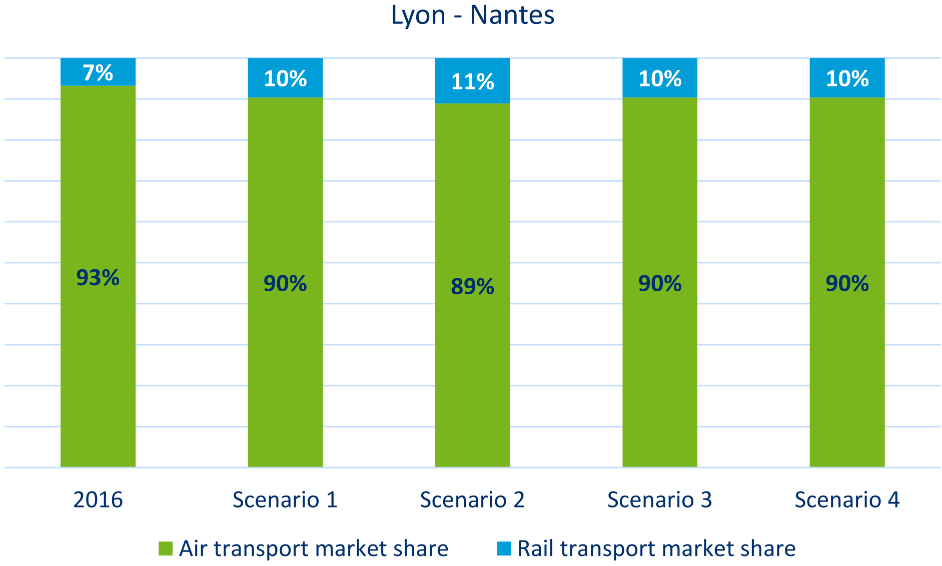


Figure 4: Scenarios impacts by mode on the origin-destination Lyon to Nantes

The **German** rail network has a greater density and homogeneity than the French network, which corresponds to a rather different geography, with several large cities and a capital situated on the outskirts of the country, rather than at its centre. The railway lines link the main urban centres. Furthermore, we note that GDP per NUTS-2 varies little according to the regions, which translates into a rather homogeneous production of wealth on the German territory. There are a few rail hubs that focus on high-speed lines, but these hubs are distributed fairly evenly and correspond to the major German cities. For the analysis of market share impact, the connection Frankfurt (Main) to Hamburg is considered. The city of Frankfurt has one of the largest railway infrastructure in the country, which is also supported by the railway station at the city's airport. Frankfurt International Airport is a major international hub, and was Germany's busiest airport in 2016 with almost 61 million passengers, with almost 50% being connecting passengers. Hamburg has five railway stations and Hamburg Airport is the fifth busiest airport in Germany. More than 16.2 million passengers travelled through it in 2016. By train, Frankfurt (Main) to Hamburg takes an average of 4 hours 49 minutes and 3 hours 43 minutes with the shortest connection; by plane, it takes 1h05.

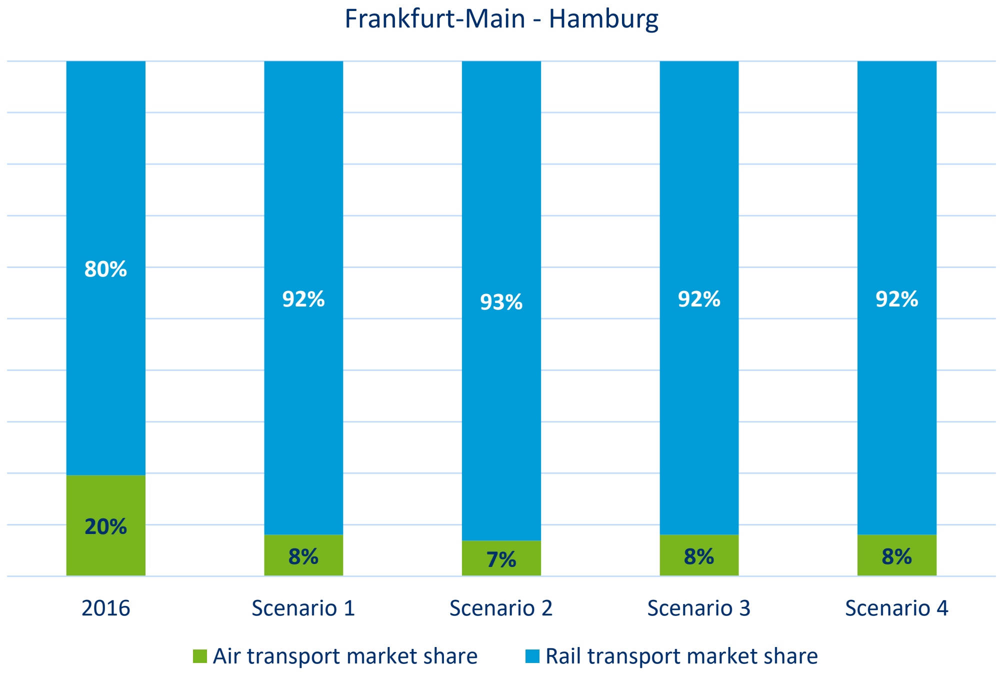


Figure 5: Scenarios impacts by mode on the origin-destination Frankfurt-Main to Hamburg

In 2016, 80% of journeys are made by train and the remaining 20% by air. Across the different scenarios, we observe that the market share of air travel is down by about 12 percentage points, reaching 8% of the market share in Scenario 1 and 7% in Scenario 2. This decrease in origin-destination air transport market share can be explained by the increase in air fares, which has been assumed in our analysis. In addition, both airports are located outside the cities, which increases the door-to-door travel time, which may in turn considerably increase the travel time by air.

In **Spain**, the railway network is organised in a hub-and-spoke pattern, with Madrid at its centre. In addition, Spain has an extensive high-speed rail network, which is the longest in Europe. This is the result of a policy of investment in the expansion of high speed. Nevertheless, this network has the particularity of having four different types of gauge, but since 1980 a policy of unification has been carried out on the Spanish railway network. The Barcelona-Madrid market is analysed in terms of market share impacts across the considered scenarios. Barcelona is served by two major train stations. Barcelona has an extensive rail network that connects it to the high-speed network that serves major Spanish cities as well as France. Barcelona airport is located outside the city. It is the second largest airport in Spain with 44.1 million passengers in 2016. It takes 2.5 hours at best to reach Madrid from Barcelona by train, but the average time is 3 hours 23 minutes. By plane the travel time is 1. 25 hour.

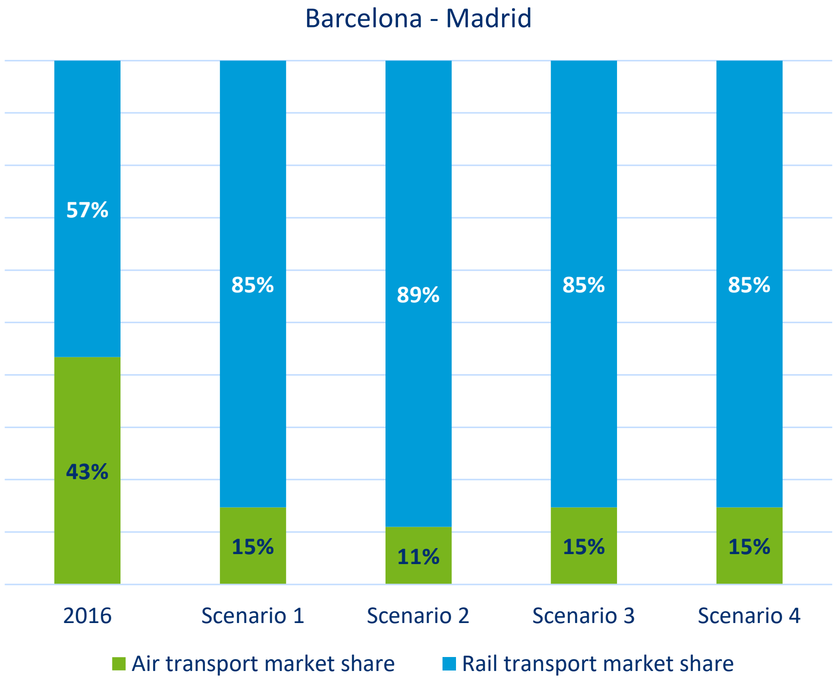


Figure 6: Scenarios impacts by mode on the origin-destination Barcelona to Madrid

The market share graph shows a rather nuanced market share distribution in 2016; rail slightly dominates with 57%. Introducing a price increase to the air transport market, the rail market shares increases to 85% in Scenario 1 and 89% in Scenario 2. The significant change in market shares may be due to a loss of competitiveness of air transport compared to rail transport due to a time saving (if considering door-to-door total travel time).

Overall, the assessment of the modal choice model has shown the very strong sensitivity of passenger demand to changes in the level of air and rail prices whatever the considered country. This strong price sensitivity leads to close market changes evolution in the considered scenarios. Changes in air and rail fares tend to be the main drivers of potential market shares substitutions between both transport modes, whatever the considered evolutions in socio-economic indicators.

2.3.1.2 Mercury and R-NEST experiments

We here develop the scenario models variously considered in Modus to compare their respective impact outcomes. They are **detailed as experiments for the modelling**, using the same scenario numbers (1-3; scenario 4 is not simulated at this stage of Modus). (1) serves as the current baseline and depicts the 2019 air and rail traffic situation. The current baseline is then extrapolated into a future baseline (2a), and a short-haul ban is further introduced as (2b). The scenario with strong growth enabled by technological innovation is run as experiment 3a.

Mercury experiments

As previously indicated, originally Mercury focused on the modelling of the gate-to-gate (G2G) phase of the passenger itineraries. Mercury is a stochastic agent-based model. The model has been expanded to consider multimodal journeys. Figure 7 presents the different processes and data flows required to generate the input of the mobility model (with pre-computation of passenger itineraries, flight schedules, flight plans and rail alternatives) and post processing of the first-last mile processes. As indicated, the approach described covers all three phases of transport: with a strategic layer generating demand and supply flows and rail alternatives, a pre-tactical layer which translate those flows into individual schedules and passenger itineraries, and the tactical execution of the itineraries in the tactical layer. Further details are in Deliverable D4.2.

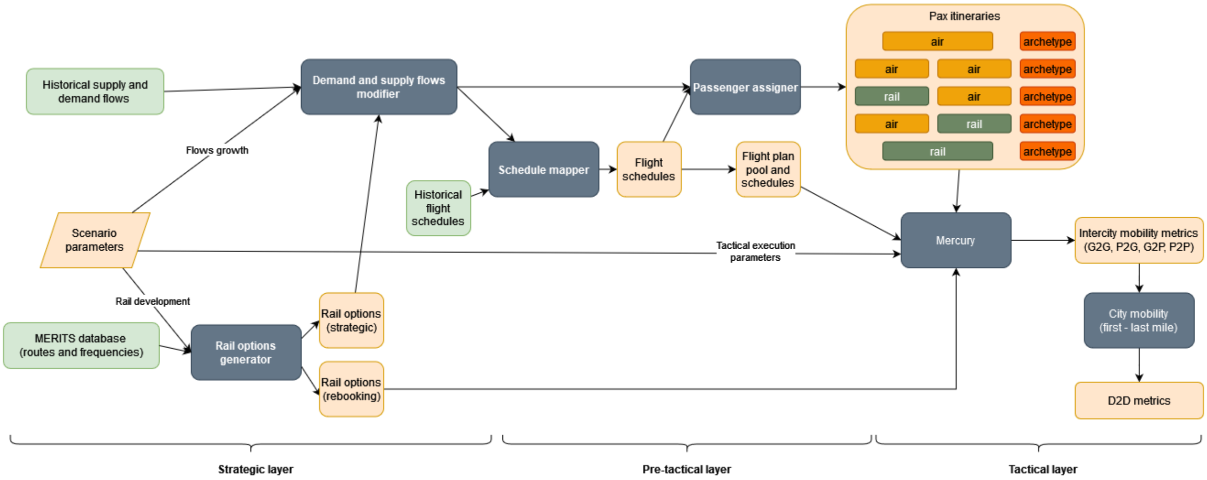


Figure 7: Mercury Modus implementation

As illustrated in Figure 8, the demand and supply flows modifier component lies in the strategic layer, its role being to produce the future flows, and future passenger itineraries. Flows represent the future supply of seats, while passenger itineraries represent the future demand in an aggregated volume of passengers. The generated supply and demand volumes are varied across scenarios presented. In order to prepare the future flows and itineraries, we started from the historical (2014) flows and itineraries. These were increased using EUROCONTROL's Challenges of Growth forecasts [2] [more specifically using the traffic multipliers related to the appropriate forecast, and regional values of the specific flows itineraries. Further details, and the key Mercury parameters for the experiments described in Table 4, are in Deliverable D4.2. These capture the key features of the multimodal scenarios, whilst some additional analyses, e.g. deploying the G2G features of Mercury, will be undertaken for the final Modus workshop (in Q1 2023), materials for which will also be cited in the Modus Final Periodic Report. See also Section 2.3.2.2 for wider future work to be conducted.

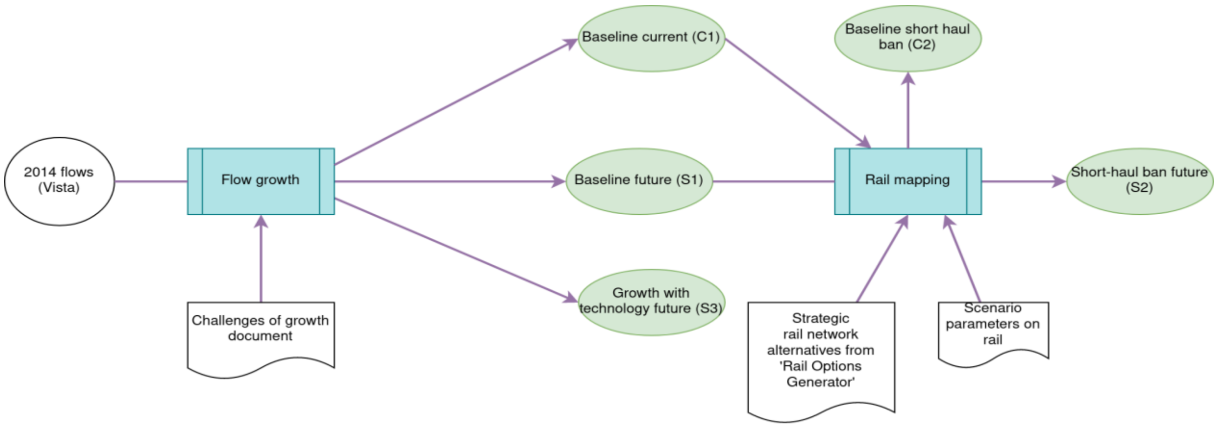


Figure 8: Depiction of flow and itinerary creation for Modus scenarios

Table 4: Mercury experiments: design

Mercury experiment #	Experiment	Disruption	Air layer[1]	Rail layer
1	Current baseline	No	Air traffic and passenger itineraries for 2019	Rail traffic 2019
1*		Yes[2]		
2a	Future baseline	No	2040 base traffic growth	2040 rail network[3]
2a*		Yes		
2b	Future baseline + short-haul ban[4]	No		
2b*		Yes		
3a	Future high growth	No	2040 high traffic growth	
3a*		Yes		

R-NEST background and experiments

Most of the simulations related to ATM have been developed around microscopic and detailed models that allow the aircraft to fly precise three-dimensional routes. In this flight centric network study, the approach is more generic and can be defined as macroscopic with a high level of detail chosen in order to model the ATM network behaviour with its associated performance indicators. The EUROCONTROL R-NEST tool focuses on the gate-to-gate flight phase, modelling the full flight trajectory and all the airside (i.e. airspace and route structures) and landside (i.e. airport) components of the European air transport network. For the Modus project, the model has been extended to encompass air passenger itineraries and rail journeys.

From the summer 2019 historical flight schedules, the air demand is expanded to the most-likely future level (i.e. for the year 2040). Then this flight demand goes through the rail layer and passenger

[1] Air traffic growth: for future experiments 2 and 3, the "regulation and growth" (most likely scenario) and "global growth" forecasts, respectively, are used in EUROCONTROL's Challenges of Growth forecasts [2].

[2] **Disruption**: a description of the disruptions applied is to be found with Table 4, which present the Mercury experiment results.

[3] **Rail network in 2040**: in these scenarios the rail ***frequencies*** in Germany, France, Spain and Italy are adapted as described in Appendix A.2. No new routes or links per se are anticipated to impact these countries in terms of the short-haul bans or disruptions.

[4] **Short-haul ban**: flights with a great circle distance lower than 500km are not operated by air in Germany, France, Spain and Italy, whereby a corresponding rail service exists to carry these passengers.

itineraries model to compute the passengers travel time and to shift air demand to rail depending on the assumptions and rules of the simulated scenario. Then R-NEST is able run the delay model, to detect and to solve the observed congestion at the network level by applying the Network Manager's mechanisms to respond to network constraints in a similar way to real operations. Figure 9 illustrates the three main steps: (1) Model calibration: to update (i.e. fine-tune) the R-NEST delay model and to measure reference network performance metrics. (2) Future traffic sample: this phase uses the flight increase component within R-NEST to build the future reference traffic sample. (3) Performance assessment: for each scenario retained, simulation runs are performed to evaluate the impact of the high-speed rail development over the air traffic demand. Further details are in Deliverable D4.2. The first three scenarios have been refined in view of the modelling of passenger mobility evolution, air and rail transport network (current and future). Three main scenarios and sub-scenarios are described in Table 5.

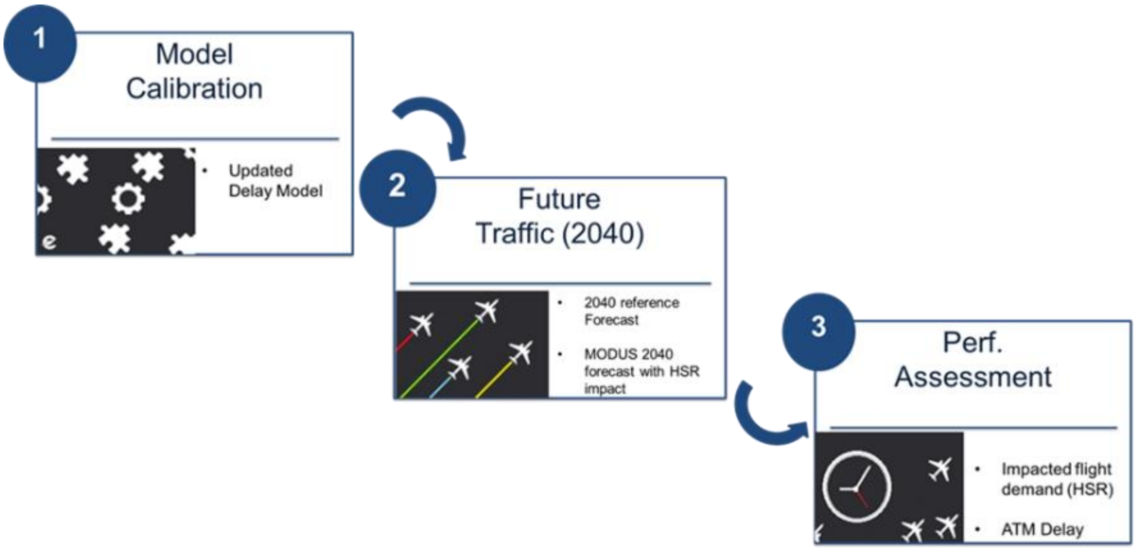


Figure 9: R-NEST modelling and assessment approach

Table 5: R-NEST experiments: design

R-NEST experiment	Description	Disruption	Air characteristics	Rail characteristics
1	Current baseline		2019 traffic levels	2019 rail network
2a	Future baseline		2040 base traffic growth	
2b	Future baseline + short-haul ban^		2a minus shifted air demand to rail on short-haul ban routes	
2c	Experiment 2a + extra rail competition	No	2b with extra rail competition; some flights thus no longer operated	2040 rail network
3a	Future high growth		2040 high traffic growth	

3b	Future high growth + short-haul ban[5]	3a minus shifted air demand to rail on short-haul ban routes
3c	Experiment 3b + extra rail competition	3b with extra rail competition; some flights thus no longer operated

Note that experiment **3b and 3c** in the R-NEST experiments may be **considered as 'additional'** to the Mercury 3a experiments, in that the former consider a short-haul ban within the context of a high growth future.

2.3.1.3 Overview comparison of the R-NEST and Mercury models

The comparison of the two models highlights the different elements of these, and potential areas for improvement by considering additional modules implemented, for example. Whereas Mercury integrates explicit passenger itineraries, and disruptions can be modelled, R-NEST does not. On the other hand, R-NEST employs a higher resolution airspace. The integration of multimodality is also approached differently. The discussion of the extension of these models by a respective rail layer or module has been subject of valuable discussions and exchanges within the Modus project, and hence resulting advancements of each model.

Table 6: High-level comparisons of Mercury and R-NEST models

Feature	Mercury	R-NEST
Scenarios	• Baseline 2019 & 2040 • Short-haul ban 2040 in Italy, France, Germany, Spain <500 Km • Significant growth with strong technological support by 2040	• Baseline 2019 & 2040 • Short-haul ban 2040 in Italy, France, Germany, Spain <500 Km • Significant growth with strong technological support by 2040 • Short-haul ban & extra rail competition 2040 • High traffic growth & extra rail competition 2040
Period modelled	Busy September day: 2019, 2040	1st August-30th September: 2019, 2040
Inclusion of explicit passenger Itineraries	Yes	No
Modelling of disruption	Yes	No
Air layer	• Initial flows from 2014 • *Challenges of Growth 2018* • Experiments 2 increase by 53% • Experiments 3 increase by 84%	• Initial flows 61 days from 1st August 2019 • *Aviation Outlook 2050* • Experiments 2 increase by 25% • Experiments 3 increase by 51%
Higher resolution airspace	No	Yes

[5] Short-haul ban: same as Table 4.

Multimodality	• Rail network replaces whole or part of the flight. • For short-haul ban pax transfer to rail network where possible. • For multimodality, hub airports identified, first/last leg replaced	• For short-haul ban scenarios: rail considered • For air and multimodal journeys, D2D times computed • Air pax switch to rail in case of reduction of travel time by 1h • Air mode will be ceased in case of >=20% pax switch to rail

2.3.2 Mercury mobility model results

2.3.2.1 High-level results

Table 7: Mercury experiments: results

Mercury experiment #	Description	Disruption	Air characteristics	Rail characteristics	KPAs and metrics			
					Flight and air pax basis	**Capacity**	**Predictability**	**Environment**
					Flights operated/pax carried	**D2D average times**	**Average flight waits**	**Gate-to-gate CO_2**
					and **flights/pax cancelled**	***and*** **pax carried by rail**	***and*** **pax cancelled by rail**	***and*** **main mode CO_2 saved**
1	Current baseline	No	2019 traffic levels	2019 rail network	Total flights: **31 080** Total pax: **4 029 k** Network pax: **1 950 k** 4C pax: **461 k**	D2D avg. network: **467 mins** D2D avg. 4C: **422 mins**	Flight avg. wait network: **149 mins** Flight avg. wait 4C: **122 mins**	G2G CO_2 network: **94 kg/pax** G2G CO_2 4C: **99 kg/pax**
1*		Yes	2019 traffic levels		Total flights cancelled: **898** Network pax cancelled: **69.8 k**	Network pax carried by rail: **4.81 k**	Network pax cancelled: **93%**	Main mode CO_2 saved: **20 kg/pax**
2a	Future baseline	No	2040 base traffic growth	2040 rail network	Total flights: **44 900** Total pax: **5 920 k** Network pax: **2 720 k** 4C pax: **658 k**	D2D avg. network: **469 mins** D2D avg. 4C: **424 mins**	Flight avg. wait network: **133 mins** Flight avg. wait 4C: **112 mins**	G2G CO_2 network: **86 kg/pax** G2G CO_2 4C: **91 kg/pax**
2a*		Yes			Total flights cancelled: **1460** Network pax cancelled: **104 k**	Network pax carried by rail: **7.27 k**	Network pax cancelled: **93%**	Main mode CO_2 saved: **19 kg/pax**

2b	Future baseline + short-haul ban	No		Total flights: **43 500** Flights banned: **1360** Pax banned: **110 k**	D2D avg. network: **445 mins** D2D avg. 4C: **402 mins**	Flight avg. wait network: **137 mins** Flight avg. wait 4C: **112 mins** Pax cancelled: **1.6 k**	G2G CO_2 network: **87 kg/pax** G2G CO_2 4C: **92 kg/pax**
2b*		Yes		Total flights cancelled: **1170** Network pax cancelled: **95.0 k**	Network pax carried by rail: **3.14 k**	Network pax cancelled: **97%**	Main mode CO_2 saved: **20 kg/pax**
3a	Future high growth	No	2040 high traffic growth	Total flights: **52 200** Total pax: **7 190 k** Network pax: **3 220k** 4C pax: **764 k**	D2D avg. network: **439 mins** D2D avg. 4C: **394 mins**	Flight avg. wait network: **125 mins** Flight avg. wait 4C: **101 mins**	G2G CO_2 network: **85 kg/pax** G2G CO_2 4C: **89 kg/pax**
3a*		Yes		Total flights cancelled: **1530** Network pax cancelled: **122 k**	Network pax carried by rail: **17.5k**	Network pax cancelled: **86%**	Main mode CO_2 saved: **18 kg/pax**

Key

* these experiments are subject to disruption.

"**4C**" indicates values that refer to the four countries in which the short-haul ban is applied (GCD < 500 km not operated by air in Germany, France, Spain and Italy, where rail alternatives exist.

"**Network**" refers to values relating to the OD pairs within the 176 European airports for which Modus applied city/airport archetypes.

"**Total**" refers to the total modelled ECAC values.

Considering the Mercury results of Table 7, the number of modelled fights and passengers carried by air is shown, by experiment, in the first metrics column ("flight and air pax basis"). The blue-shaded rows present the disrupted experiments, the unshaded rows present the nominal experiments. We start with the latter. Whilst by definition all of the passengers (110 k) on the modelled short-haul banned flights (row 2b) are shifted to rail services, only just over 1% are not reaccommodated by train (1.6 k pax are cancelled due to exceptional circumstances, e.g. substitute air-rail-air itineraries being impractical). Under "capacity", the D2D times in the smaller four-country (4C) network are all logically lower than corresponding "network" values of the wider (176-airport) network.

Of particular interest is the fact that, in both cases, the current (1a) and future (2a) baselines produce similar values, as do mutually the short-haul ban (2b) and future high growth (3a) experiments (the high growth with technology scenario includes modest improvements in D2K, K2G, G2K and K2D times by 2040). The data shown are currently missing elected buffer (wait) times, whilst we acquire these for rail journeys. Under "predictability", the '**flight average wait**' times reflect the average wait time for flights for passengers with connecting itineraries, taking into account minimum connecting times at airports. These **improve (decrease) with traffic growth** down the table, and are always smaller for the 4C countries (with or without the bans in operation). Under "environment", for the same experiments,

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the **G2G CO_2 values per passenger** are shown (for the main rail and air modes travelled, i.e., currently excluding airport access and egress CO_2). These are fairly uniform across the experiments, notwithstanding the improvements in emission rates cited in Deliverable 4.2 for air and rail by 2040.

For the **tactical disruption experiments** (1*, 2a*, etc. - blue-shaded rows) it is assumed that two regions are impacted by a large air disruption, and rail is used to route some of the affected passengers. All the rail schedules are considered, regardless of the countries involved, duration, or speed (high-speed rail or not). The regions of Madrid, with Madrid Barajas, and Paris, with Paris Charles de Gaulle and Paris Orly, are used. At these airports, 90% of short-haul (and 50% of long-haul) flights are cancelled, and modelled as if advised to all impacted passengers the day before (D-1), and operating (D) 0001-1400 (local time). The cancelled short-haul flights are compared to the rail network and the cities that can be reached directly by train. For experiments 1*, 2a* and 2b*, these passenger trips are cancelled if no rail service is available, or if the rail journey takes more than twice as long as the original air trip. For experiment 3*, this tolerance is extended to thrice the length, to reflect the fact that under this scenario new technologies render the rail option of a higher utility, notwithstanding the extra trip length: see Deliverable 4.2 for details. (The long-haul disruption is not yet modelled for any impacts.) The **increased utility of rail in experiment 3*** allows for a higher shift to rail (17.5 k pax) and thus **fewer (86%) passengers with cancelled trips** (under "predictability"). This rate is highest (97%) under the short-haul ban (2b*), whereby air trips are longer on average and more difficult to replace by rail. The **CO_2 'saved' per passenger** (under "environment”) as a result of the disruption-cancelled short-haul flights across all experiments, taking into account the corresponding emissions for those substitute rail journeys that are possible, is **quite uniform**. This fairly indicative metric currently excludes airport access/egress, transfer modes, and, indeed, the **social cost of the cancelled trips**.

Despite the different approaches of the Mercury and R-NEST models (see Table 6), it is to be noted that the number of flights and nominal G2G CO_2 modelled in Table 7 (Mercury) and Table 8 (R-NEST) are in pretty close agreement.

2.3.2.2 Next steps for the Mercury model

As mentioned in Section 2.3.1.2, deploying the G2G features of Mercury, including stochastic delay models, will be undertaken in near-term future work. Along with improved rail data (full schedules and delays still to be modelled), this will strengthen the range and types of **predictability metrics** that can be modelled. It would also be desirable in future work to model **explicit rail capacities**, plus include an assessment of **elected buffer (wait) times** (for air and rail), which need to be acquired/modelled by the team for rail journeys. In the D2D model, further refinements will be incorporated regarding the local itineraries of passengers making journeys to stations instead of airports (under the short-haul bans and during disruption) and for intermodal connection times.

Furthermore, various **additional calculations could be made for the CO_2 savings** calculated during disruption, for example limiting these to the disrupted passengers who are actively re-booked, compared with their original air journey, rather than counting all the cancelled flights as 'saved' CO_2, regardless of the outcome for the passenger (e.g. making no trip at all). Sensitivities regarding **short-haul ban thresholds** and assumed improvements in air and rail emissions rates could also be assessed, including relating to CO_2 output under different technological and energy-generation assumptions.

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2.3.3 R-NEST mobility model results

2.3.3.1 High-level results

Table 8: R-NEST experiments: results

						Metrics / KPAs							
						Capacity						Environment	
R-NEST experiment #	Description	Disruption	Air characteristics	Rail characteristics	Avg flights per day (flights)	Avg banned/moved to rail Flights per day (flights)	Avg Total Delays (All Causes) per Flts (min)	Avg ATFCM delays per flights (min)	Avg reactionary delays per flights (min)	Avg non-ATFCM delays per flights (min)	Avg Fuel burnt per day (kt)	Avg CO_2 per day (kT)
1	Current baseline	No	2019 traffic levels	2019 rail network	34800	-	14.9	2.3	7.2	5.5	179	565
2a	Future baseline	No	2040 base traffic growth	2040 rail network	43500	-	9.2	0.4	3.7	5.0	234	741
2b	Future baseline + short-haul ban	No	2a minus shifted air demand to rail on short-haul ban routes	2040 rail network	42600	929	9.0	0.4	3.5	5.1	233	735
2c	Experiment 2a + extra rail competition	No	2b with extra rail competition; some flights thus no longer operated	2040 rail network	42090	1450	8.9	0.4	3.5	5.1	232	731
3a	Future high growth	No	2040 high traffic growth	2040 rail network	52700	-	15.9	3.7	6.2	5.9	286	904
3b	Future high growth + short-haul ban	No	3a minus shifted air demand to rail on short-haul ban routes	2040 rail network	51500	1260	13.8	3.0	5.1	5.8	283	895
3c	Experiment 3b + extra rail competition	No	3b with extra rail competition; some flights thus no longer operated	2040 rail network	51100	1580	13.7	2.9	5.0	5.7	282	893

Next to the similar outcomes in regard to nominal G2G CO_2 of the two models, the R-NEST outcomes provide additional insights into key performance areas such as predictability, including different **delay metrics**. As might be expected, the 'average total delays (all causes) per flights (min)' increases with increasing traffic growth. Introducing a short-haul ban to the high growth Experiment 3b leads to a reduction in this metric.

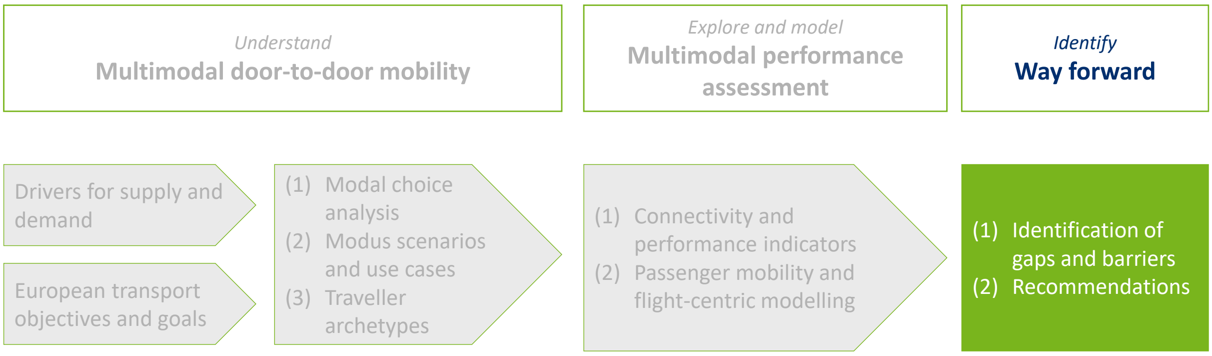
The R-NEST model also gives an indication regarding the **number of flights being moved to rail** per day in case of a short-haul ban introduced to routes below 500km. Adding extra rail competition in Experiment 3c, increases the number of flights being moved to this mode, potentially due to an assumed higher rail utility.

2.3.3.2 Next steps for the R-NEST model

Further improvements of the R-NEST model in regard to integrating multimodal aspects include:

- Integration of train schedules
- Improved rail layer and travel time modelling (e.g. different transit times linked to the size of the city and the station)
- Improved travel itineraries modelling including connections to allow passenger's travels combining rail & air transportation mode

2.3.4 Identification of gaps and barriers



During the course of the Modus project interactive participation of experts of different transport domains and beyond has been pursued in order to discuss and evaluate the results obtained within Modus. In addition to this, the goal was to gather, discuss and assess various perspectives and insights in regard to what constitutes truly multimodal mobility within Europe, and which areas of improvement need to be addressed and prioritised.

A 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 driver Intermodal Integration was recognized as crucial 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 as well as for leisure travel by rail; however, the consulted experts assumed that both leisure and business travel by air may stay relatively stable or even decline. (see Modus Deliverable D3.1)

In addition to this, the first Modus workshop in January 2021 had a high number of attendees (more than 80 people), representing reasonable cross-section of air and rail expertise, with a mix of operators and researchers particularly involved in other multimodality projects. The exchange and discussion of the workshop was focused on the following topics:

- 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?

The assessment of participants within this workshop highlighted the most promising aspects to improve the performance of the future European transport system in 2040+ (see Table 9 below). The table shows potential (strong) enablers (in bold) and potential barriers regarding the improvement of the multimodal European transport system. 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.

Table 9: Potential enablers and barriers for future multimodal transport

High-level category	Enablers	Barriers
Infrastructure improvements by 2040	**Information/ data sharing** **IT System D2D / passenger data sharing /** **Collaborative processing across modes** **Trust between modes/collaboration** Complementarity between air & rail for security Connectivity	Infrastructure capacity Airport design Network integration Security
Business models evolution by 2040	**Regulation to ensure level playing field for service providers** **Intermodal transfer accessibility and efficiency** **Better passenger disruption services & tools** **ICT on D2D** **Passenger flow at airport** Provision of a seamless, single booking tool Regulatory framework	Data sharing and management Trust between modes / collaboration
Improvement for passengers 2040	**Regulations** **Booking and ticketing (tools)** **Information to improve passenger experience** **Journey planning** **Personalisation of travel** **Luggage handling infrastructure** Green travel Ticketing innovations Accessibility and comfort	Price and cost Passenger journey experience Information in disruption (Improved stakeholder stress & inclusivity)

The second Modus workshop (February 2022) stood out by its uniqueness in bringing together the aviation and railway communities to exchange and discuss challenges and opportunities of multimodality. Participants from different transport domains, especially air and rail, provided feedback and discussion on the Modus scenarios and use cases, and highlighted current gaps and barriers as well as opportunities necessary for increased multimodality. One focus was placed on passenger needs and requirements in regard to door-to-door travel.

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What do travellers want?

- Seamless travel / D2D offers
- Coordinated mobility
- Guarantees / protection
- Perception of comfort and security
- Informed decision-making
- End-user-centric systems
- Affordability (depending on travel purpose)
- Reliability
- Sustainability (future driver of travellers)
- Accessibility (physical or non-physical / inclusion

Knowledge about travellers' demand is key! Potential change from an supply-push system towards a demand-push system (e.g. in rural areas)

Furthermore, several aspects were highlighted how a multimodal mobility system can be enabled. For one, it was suggested that transport strategy should move towards smart contracts with travellers, and integrated traffic management (TM) independent of the transport mode, and the importance of the link between ATM (air traffic management) and rail TMS (transport management system) was stressed. This enhanced collaboration will enable transparency on services and regulations for passengers. IT/telecom capabilities need to be aligned with transport strategy and the GDPR has to be accommodated with smart contracts, for example.

Findings from the workshop prioritise the following aspects as essential in moving towards a multimodal, integrated European transport system which requires close cooperation and coordination of all stakeholders:

- Further development of multimodality frameworks, more integrated transport solutions and on-demand services
- Assessment of technology enablers
- Data management, data sharing and provision
- Further identification and application of key performance indicators to evaluate transport performance and implemented measures
- Essential to include individual traveller needs along the journey, address their feedback and varying requirements

In addition to the air and rail expert involvement within the scope of workshops and an expert survey, several interviews were conducted to collect experts' view on the way towards multimodal air-rail transport in Europe.

Expert interview setting:

Seamless and smart door-to-door multimodality and an enhanced traveller experience are high on the agenda of all transport modes in Europe. A stronger air-rail joint mobility and cooperation are considered to play a significant role in achieving these objectives. The Modus project and other initiatives have been investigating the progress towards multimodality within Europe. It has been shown that a lot needs to be done in this regard, and we would like to ask you to share your insights on how true multimodality can be reached:

- What are the main barriers and levers to improve air + rail mobility in Europe?
- Which current or future business models can enable multimodality?
- What are needed infrastructure adaptions to make multimodality a reality?
- What are future travellers look like in terms of personalisation and required travel services?
- What should be implemented first in your sector?

Visit the Modus website for the full interviews: https://modus-project.eu/

These interviews provided further insights on business models, infrastructure or passenger experience and the way forward. In terms of future business models, collaboration and cooperation, especially between air and rail, have been strongly emphasised. This could include (enhanced) interline or codeshare agreements, as recently occurring with Deutsche Bahn in Germany becoming the first intermodal partner of the Star Alliance (https://www.staralliance.com/en/news-article?newsArticleId=4540544&groupId=20184), offering seamless and single ticketing options for passengers on air-rail journeys. Next to commercial and legal agreements between air and rail, experts suggested to look into the potential of joint ventures, or joint ownership of assets in order to optimise networks and provide new and improved services to customers. Passenger experience and environmental considerations are a significant driver of multimodality and will have an influence on future cooperation and respective business models.

Many elements contribute to a seamless door-to-door journey for travellers. One of these is the ability to book one-stop door-to-door mobility offers by only one contractual partner and via a single platform. Currently, there are undertakings that aim at integrating railway and airline standards into a common platform. Another important aspect is the provision of real-time information, especially in case of delays and distributions, and according travel management by offering rebookings to passengers. Information also plays and essential role in the personalisation of future journeys, with tailored choices, richer content and better services.

Furthermore, infrastructure developments will be a major enabler of multimodal solutions, or can impose a significant barrier otherwise. Extending the high-speed rail network in Europe, including the incorporation of airports, and facilitating the interchange and transfer between these modes, especially in terms of luggage handling, and inclusion of all travellers are key elements of enhanced multimodality. Today’s processes required in a door-to-door journey are different between air and rail in terms of check-in, security control, passport control or boarding, for example, and also exhibit potential for improvement and alignment.

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A very important and decisive enabler is the policy and regulatory framework enabling increased cooperation and seamless travel across transport modes. The rules for consumer protection need to updated to include multimodal transport, and a comprehensive framework for data sharing and protection has to be established. The expert suggest that currently issues like differences in airline content distribution (e.g. filling schedules and fares, using PNR and e-tickets) and train operations (more location codes, single tickets etc.) hinder a harmonised approach. The question of liability in terms of disruptions, delays or other irregularities has to be specified in order to set incentives for enhanced collaboration between modes.

From these various interactions and discussion with experts from the different mobility domains and beyond, the following enablers are considered to contribute in an essential way in further advancing a truly multimodal system in Europe, with a particular focus on air-rail mobility.

Figure 10: Enablers for a future air-rail multimodal system

2.4 Project Deliverables

<table>
<tr><th>Reference</th><th>Title</th><th>Delivery Date</th><th>Dissemination Level</th></tr>
<tr><th colspan="4">Description</th></tr>
<tr><td>1.1</td><td>Project Management Plan (PMP)</td><td>CO</td><td>21 September 2020</td></tr>
<tr><td colspan="4">This deliverable is a practical guidance document and specifically tailored to the requirements and processes of the project. It focuses on a short outline of the project's objectives as well as the approach in achieving these to provide the same basis for all consortium partners. The PMP also details the project management and organisation, including the organisation and roles within the consortium, and the work breakdown structure, milestones, meetings and deliverables throughout the project. Furthermore, it describes project specific processes that are implemented in order to ensure the adherence to H2020 rules and alignment with the SJU SESAR 2020 Handbook.</td></tr>
<tr><td>2.1</td><td>Data Management Plan</td><td>CO</td><td>07 November 2022</td></tr>
<tr><td colspan="4">This deliverable describes the data management procedures including the description of the datasets, data storing, preparation, processing, visualisation and security aspects, when applicable. Additionally, it outlines the principles of the FAIR framework that Modus to adheres to, as part of the Open Research Data pilot, in order to make research data findable, accessible, interoperable and re-usable.</td></tr>
<tr><td>2.2</td><td>Database structure</td><td>PU</td><td>03 May 2022</td></tr>
<tr><td colspan="4">This deliverable details the structure of the data lake, providing as well the complete information on the data sources, their relationships to each other, and all the data management techniques applied.</td></tr>
<tr><td>3.1</td><td>Modal choice analysis and expert assessment</td><td>PU</td><td>09 June 2021</td></tr>
<tr><td colspan="4">This deliverable 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. These insights contribute to modal choice analysis, use cases, and scenarios.</td></tr>
<tr><td>3.2</td><td>Demand and supply scenarios and performance indicators</td><td>PU</td><td>02 November 2021</td></tr>
<tr><td colspan="4">This deliverable presents supply and demand scenarios (time horizon: 2040), seven passenger archetypes as well as connectivity, performance and intermodal indicators. The scenarios are derived from European high-level mobility objectives, existing scenario studies as well as the work conducted within the Modus project. Each scenario focuses on particular aspects with the potential to significantly change the transport system as we see it today. Further, the deliverable discusses connectivity, performance and intermodal indicators within the Modus context.</td></tr>
<tr><td>4.1</td><td>Interface to modal choice model: methodology</td><td>PU</td><td>27 July 2021</td></tr>
<tr><td colspan="4">This deliverable describes the methodology designed and developed to translate the output results of the modal choice model into individual passenger itineraries that are going to be used by the mobility models. Additionally, it outlines so-far identified data requirements and processing needs to create valid input for the rest of the models developed in Modus: flight-centred airside model RNEST, passenger-centric airside model Mercury, and the landside model (i.e. door-to-door model).</td></tr>
<tr><td>4.2</td><td>Mobility models description</td><td>PU</td><td>8 December 2022</td></tr>
<tr><td colspan="4">This deliverable provides the architecture description of the passenger mobility model (Mercury) and the flight-centric network model (RNEST), an overview of their functionalities and implementation details.</td></tr>
<tr><td>5.1</td><td>Definition of use cases</td><td>PU</td><td>23 September 2021</td></tr>
<tr><td colspan="4">This deliverable defines a set of use cases which assist in identifying the main barriers in achieving European (air) mobility goals and how air transport can efficiently connect information and services with other transport modes for a seamless journey experience for passengers. The four use cases represent key aspects of the door-to-door journey in Europe, ranging from the impact of Flexible ticketing on re-accommodating passengers in case of disruptions, to the potential policy-incentivised replacement of Short-haul travel (air) on selected routes within Europe, and the role of Connectivity and seamless travel as well as the degree of Personalised travel.</td></tr>
<tr><td>5.2</td><td>Report on overall final project results</td><td>PU</td><td>September 2022</td></tr>
</table>

This deliverables provides an overview of the entire work performed in the Modus project, the results obtained during the course of the project, their contribution to the ATM Master Plan and provides documentation to the Modus Maturity Gate assessment.			
6.1	Communication, Dissemination and Exploitation Plan	CO	17 June 2022
This deliverable defines the dissemination, communication and exploitation strategies of the Modus project in order to maximise its outreach to targeted audience. It includes all related activities of the Modus consortium.			
6.2	Final Dissemination Report	PU	30 November 2022
The Modus final dissemination report presents the key results of the project and summarises the most important recommendations, including the final Modus brochure highlighting the key results of the project, as well as recommendations for the different target groups.			

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3 Links to SESAR Programme

3.1 Contribution to the ATM Master Plan

There are different areas of both the European Air Traffic Management (ATM) Master Plan (MP) as well as the SRIA Digital European Sky to which the Modus research results contribute.

(1) Achieving improved airport performance and access by implementing enhanced runway throughput capabilities; assess the enabling of 3-fold increase in ATM capacity, including the accommodation of additional flights at high traffic airports; reduced delays, increased network throughput and throughput at congested airports, including traffic growth forecast impact (ATM Master Plan).

Modus has developed and assessed various scenarios that depict future development paths of the air and rail sector. These include different traffic growth assumptions, both for air and rail (Deliverable D3.2 and D5.2). Applying modal choice analysis across these scenarios and for selected routes within Europe provides a variation in market shares of air-rail transport and a detailed insight and discussion into what drives the change in market shares across scenarios. Furthermore, the passenger mobility modelling approach provides an insight into the door-to-door impact across different scenarios, such as the impact of a significant short-haul shift from air to rail and the impact of disruptions on the predictability of journeys (Deliverable D5.2).

(2) The future European ATM system relies on the full integration of airports as nodes into the network (ATM Master Plan), and creating a seamless passenger experience and interoperability between different transport providers will be enabled by the complete integration of airports as multimodal nodes into the ATM network (SRIA).

First, Modus provides to the strategic objectives by detailing seven distinct passenger archetypes which enhance the understanding of factors driving the passenger experience and respective decision-making regarding door-to-door journeys (Deliverable D3.2). These archetypes are assigned with different characteristics that have an influence on the assigned travel times during the different steps of the journey, for example (Deliverables 4.2 and D5.2). Second, via an extensive consultation process involving experts from different transport domains, particularly air and rail, enablers and barriers have been identified to establish airports as multimodal nodes, inter alia (Deliverable D5.2).

(3) The impact of Modus in enabling a 10% reduction in the effects flights have on the environment; reduce CO_2 emissions, increase operational efficiency for airspace users (reduced fuel burn and flight time) as well as increased mobility with a lower environmental impact (ATM Master Plan); the research activities will aim at better understanding the impact of aviation on the environment and the ways in which ATM can reduce these effects ("Work Area 1 - ATM Excellent Science and Outreach" - Sub Work Area 1.3: Environment & Meteorology for ATM)

The complementarity and substitution between air and rail has been an intensely discussed topic recently in regard to the capability to reduce transport's environmental impact or providing a seamless travel experience. The Modus approach provides a tool to assess potential impacts of a closer cooperation or substitution effects between air and rail, especially regarding the impact on the areas of capacity (e.g., door-to-door travel times), predictability of journeys, and the environment (CO_2 emissions).

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(4) Increasing network resilience and the reliability and predictability of journey parameters, enhancing punctuality and passenger experience overall (SRIA); and placing increased focus on multimodal solutions will facilitate additional environmental benefits […] from alleviating congestion at and around airports by improving passenger flows (through predictability and single-ticketing), from helping access/egress to/from airports, using environmentally-friendly means […].

The Modus results provide a more detailed understanding of passenger expectations which contribute to evaluating different journey requirements and priorities along the journey. Furthermore, Modus use cases enable to analyse different aspects of the door-to-door journey in a more comprehensive way, discussed and assessed in detail in the Modus expert workshops. The integration and consultation of a large and diverse Industry Board from different transport domains yielded the identification of enablers as well as barriers for enhanced multimodal solutions potentially enhancing reliability and predictability of future journeys.

The research on Modus Solution provides innovative solutions in the following context, and has thus increased the level of maturity of the considered solution SOL-Modus.

(1) A renewed understanding of demand and supply evolution leading to an innovative modal choice model.

Modus provides important insights into the passenger experience by significantly improving the knowledge of travellers' preferences and expectations, and on how different factors influence the demand for air and rail transport. This includes the detailed analysis of passengers' preferences with regard to a modal choice, going beyond the mere travel time and price parameters and taking into account aspects such as environmental considerations or comfort during the journey. (Deliverables D3.1, D3.2 and D5.2). For this purpose, the Modus consortium has been making use of a comprehensive dataset acquired and built up during the project. This data collection, processing and integration process also provides very useful insight and the basis for further research focusing on multimodal transport assessment, especially in regard to air-rail transport. (Deliverables D2.1 and D2.2)

(2) A holistic modelling approach that covers the door-to-door travel and illustrates the impact on (air) transport capacity – in particular at airports – and passenger flows.

The modelling approach builds on the already well-equipped (air) mobility model "Mercury", developed by the University of Westminster and Innaxis over the past years, mostly focused on the gate-to-gate segment of passenger travel itineraries, providing both advanced and classical passenger and flight metrics. This has been extended within Modus to a much more comprehensive door-to-door context, integrating a rail layer with similar characteristics. This allows for the modelling of air-rail multimodality across the different scenarios investigated within Modus. Furthermore, this model has been complemented by the extension of RNEST to include multimodal choice for passengers. RNEST is the research version of the ATM simulation tool used by EUROCONTROL, which allows the modelling of air traffic, including flight trajectories and ATM processes. RNEST supports ATM validation and prospective studies such as the Challenges of Growth study. Across the different Modus scenarios, the model outputs provide insight into the impact on different KPAs, including Capacity, Predictability and Environment.

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Table 10: Project Maturity

Code	Name	Project contribution	Maturity at project start	Maturity at project end
SOL-Modus	Modus	Modus advances important insights into the passenger experience by significantly improving the knowledge of travellers' preferences and expectations, and on how different factors influence the demand for air and rail transport. This includes the detailed analysis of passengers' preferences with regard to a modal choice. The advancement of a holistic modelling approach that covers the door-to-door travel chain, integrating flight-centric and rail layer modelling, and illustrating the impact on (air) transport capacity – in particular at airports – and passenger flows.	Pre-TRL1	TRL1

3.2 Maturity Assessment

Modus solution

The Modus Solution aims at developing a modelling approach for the assessment of seamless door-to-door multimodality and passenger experience in Europe. The Modus approach is applied to evaluate the impact of an improved, joint air-rail transport system between various city pairs, characterising the contribution of air traffic management (ATM) and air transport to the improvement of travellers' multimodal journeys.

The Solution deploys passengers' modal choice decisions based on a combination of airport and railway connectivities, city archetypes and respective catchment areas. This enables door-to-door journey modelling for a variety of passenger types, using the modal choice modelling output to adjust individual passenger itineraries in the air-rail network.

As a further contribution, the Solution considers various future scenarios that depict different potential development pathways of air-rail mobility, including a significant short-haul shift from air to rail, traffic growth with strong technological support, or a move towards a more decentralised, remote and digital mobility. Based on this, the Modus modelling approach can be used as a tool to assess the resulting impacts on capacities, predictability and the environment across these scenarios and for multimodal journeys.

Table 11: ER Fund / AO Research Maturity Assessment

ID	Criteria	Satisfaction	Rationale - link to deliverables - Comments
TRL-1.1	Has the ATM problem/challenge/need(s) that innovation would contribute to solve been identified? - Where does the problem lie? - Has the ATM problem/challenge/need(s) been quantified that justify the research done? Note: an initial estimation is sufficient	Achieved	The ATM problem/ challenge has been formulated as 'citizens expect an increasingly seamless mobility experience, where the passenger experience will be smooth, safe and cost-efficient, with minimum delays, transfers and hassle. Implementing the multimodal mobility concept means that passengers shall not need to worry about selecting the most appropriate means of travel. Aviation and air transport shall support a safe, efficient and green travel experience and promote use of the most appropriate means of transport. In this way, aviation shall play its part in the global greening of transport and address its own issues of congestion, delays and suboptimal passenger experience.' In line with this, the Modus solution contributed to the analysis of future multimodal transport evolution in Europe in particular of air transport and its complementarity/competition with rail in an integrated multimodal system. The project provided to the understanding of customer, market and societal expectations and opportunities, leading to a customer-centric transport system: Modus has built scenarios of multimodal supply evolutions that reflect key challenges of different high-level transport agendas, including the SESAR SRIA, the ATM Master Plan, or the Sustainable and Smart Mobility Strategy (Modus Deliverable D3.2). The Modus project developed an integrated modelling approach which includes: • A detailed overview of mobility demand and supply drivers, including an expert assessment to prioritise different factors as well as the quantification of selected factors for the modal choice analysis. (Deliverables D3.1 and 3.2) • A comprehensive dataset (partially publicly available) which enables a better and more detailed understanding of the interaction between air and rail transport in Europe. (Deliverables D2.1 and D2.2) • The development of data-driven models of air and ground passenger transport in Europe to assess the impact across these scenarios on airside and landside processes and capacities; including the development of a unique air-rail layer model integrating door-to-door transport. (Deliverables D4.1 and D4.2) • The identification and assessment of a set of multimodal performance and connectivity indicators that reflect the multimodal nature of the transport system and which enable measuring the performance of the system (e.g., in regard to the KPAs Capacity, Predictability

ID	Criteria	Satisfaction	Rationale - link to deliverables - Comments
			and Environment) and the further evolution into a multimodal performance framework. (Deliverables D3.2, D4.2 and D5.2)
TRL-1.2	Have the solutions (concepts/capabilities/methodologies) under research been defined and described?	Achieved	The solution and the respective concepts and capabilities have been defined and described and reported to the SJU: The Modus Solution aims at developing a modelling approach for the assessment of seamless door-to-door multimodality and passenger experience in Europe. The Modus approach is applied to evaluate the impact of an improved, joint air-rail transport system between various city pairs, characterising the contribution of air traffic management (ATM) and air transport to the improvement of travellers' multimodal journeys. The Solution deploys passengers' modal choice decisions based on a combination of airport and railway connectivities, city archetypes and respective catchment areas. This enables door-to-door journey modelling for a variety of passenger types, using the modal choice modelling output to adjust individual passenger itineraries in the air-rail network. As a further contribution, the Solution considers various future scenarios that depict different potential development pathways of air-rail mobility, including a significant short-haul shift from air to rail, traffic growth with strong technological support, or a move towards a more decentralised, remote and digital mobility. Based on this, the Modus modelling approach can be used as a tool to assess the resulting impacts on capacities, predictability and the environment across these scenarios and for multimodal journeys.
TRL-1.3	Have assumptions applicable for the innovative concept/technology been documented?	Achieved	The assumptions for the activities and research questions investigated in Modus are documented in the respective deliverables: • The assumptions for the development of multimodal scenarios are described in Deliverable D3.2. • Analysis and clustering of European strategic agendas for mobility; identification of main topics having a significant influence on the shape of air-rail multimodality. • The modal choice analysis, its underlying methodology and respective parameters are described in D3.1, D3.2 and D5.2.

ID	Criteria	Satisfaction	Rationale - link to deliverables - Comments
			• Identification and parametrisation of independent and dependent variables in the modal choice model; Application of two-stage decision model; Estimation of price elasticities and demand represented as market shares. • The derivation of door-to-door use cases and respective assumptions are described in D5.1. • Identification of passenger journey related improvements, based on European high-level objectives; Validation and discussion of use cases and derivation of recommendations for implementation in expert workshop • The passenger mobility modelling approach and underlying assumptions are outlined both in D4.1, D4.2 and D5.2. • Further advancement of Mercury model, integrating rail layer to provide multimodal modelling tool, based on passenger itineraries; parametrisation of scenario parameters and assessment regarding impact on predictability, capacity and environment KPAs in D5.2.
TRL-1.4	Have the research hypothesis been formulated and documented?	Achieved	The high-level and detailed objectives have been described at the proposal stage, and are addressed in the respective deliverables that detail the innovative concepts outlined in regard to TRL-1.3 above. A comprehensive overview of the research hypotheses and the respective approaches are documented in Deliverable D5.2. The research questions are as follows: 1. What are drivers of future supply and demand of a multimodal European mobility system? 2. What are potential future joint air-rail mobility pathways for Europe? 3. Which drivers influence (and to what degree) passengers‘ choice for air-rail mobility? 4. 4. How can the use of rail be integrated into modelling door-to-door mobility, including multimodal passenger itineraries?
TRL-1.5	Do the obtained results from the fundamental research activities suggest innovative solutions (e.g. concepts/methodologies/capabilities?)	Achieved	The research on Modus Solution provides innovative solutions in the following context:

ID	Criteria	Satisfaction	Rationale - link to deliverables - Comments
	- What are these new concepts/methodologies/capabilities? - Can they be technically implemented?		(1) Modus provides important insights into the passenger experience by significantly improving the knowledge of travellers' preferences and expectations, and on how different factors influence the demand for air and rail transport. This includes the detailed analysis of passengers' preferences with regard to a modal choice, going beyond the mere travel time and price parameters and taking into account aspects such as environmental considerations or comfort during the journey. (Deliverables D3.1, D3.2 and D5.2). For this purpose, the Modus consortium has been making use of a comprehensive dataset acquired and built up during the project. This data collection, processing and integration process also provides very useful insight and the basis for further research focusing on multimodal transport assessment, especially in regard to air-rail transport. (Deliverables D2.1 and D2.2) (2) A holistic modelling approach that covers the door-to-door travel and illustrates the impact on (air) transport capacity – in particular at airports – and passenger flows. The modelling approach builds on the already well-equipped (air) mobility model "Mercury", developed by the University of Westminster and Innaxis over the past years, mostly focused on the gate-to-gate segment of passenger travel itineraries, providing both advanced and classical passenger and flight metrics. This has been extended within Modus to a much more comprehensive door-to-door context, integrating a rail layer with similar characteristics. This allows for the modelling of air-rail multimodality across the different scenarios investigated within Modus. Furthermore, this model has been complemented by the extension of RNEST to include multimodal choice for passengers. RNEST is the research version of the ATM simulation tool used by EUROCONTROL, which allows the modelling of air traffic, including flight trajectories and ATM processes. RNEST supports ATM validation and prospective studies such as the Challenges of Growth study. Across the different Modus scenarios, the model ouputs provide insight into the impact on different KPAs, including Capacity, Predictability and Environment (Deliverables D4.1, D4.2 and D5.2). The technical implementation of the adaptation of these two models has been feasible.
TRL-1.6	Have the potential strengths and benefits of the solution identified and assessed? - Qualitative assessment on potential benefits. This will help orientate future validation activities. Optional: It may be that quantitative information already exists, in which case it should be used.	Achieved	The solution SOL-Modus and its potential strengths and benefits have been identified and described in the following: Modus provides an innovative modal choice model, renewing the understanding of passengers demand evolution in face of the new economic and environmental challenges, informed with a more complete analysis of the demand drivers and based on many data sources including rail data.

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			Modus has been an opportunity to calibrate Mercury against RNEST for what concerns the air transport system. Modus provides the tools for future prospective studies on multimodality. In particular regarding the design and implementation of an integrated, intermodal air-rail transport system (Strategic Research and Innovation Agenda (SRIA) Action Area 1.2): Modus provides an integrated modelling approach towards the European transport system, including both air transport and rail, which enables a thorough assessment of the gaps and potential solutions required to meet European high-level objectives in this area. By this, the project also 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 a multimodal Industry Board as well as expert from relevant areas.
TRL-1.7	Have the potential limitations, weaknesses and constraints of the solution under research been identified and assessed? - The solution under research may be bound by certain constraints, such as time, geographical location, environment, cost of solutions or others. - Qualitative assessment on potential limitations. This will help orientate future validation activities. Optional: It may be that quantitative information already exists, in which case it may be used.	Achieved	The solution SOL-Modus and its potential limitations, weaknesses and constraints have been documented in Deliverable D5.2 "Lessons learned" and constraints are being addressed in terms of further research development and focus. A key challenge for the project has been the robust parameterisation of the scenario variables in the simulation and other quantitative modelling. The multimodal focus in particular, for air and rail joint mobility, requires coherent datasets for supply and demand modelling. The availability of this type of data is different for the various transport modes and therefore enormous extra effort had to be invested in data acquisition and processing to obtain disaggregated route-level data for the different markets and scenarios considered in the Modus analysis. This has also required some data filling and various assumptions to be discussed and agreed across the team, over several months, particularly due to missing future rail data (although missing current rail data was also a very great challenge). Overall, rail data have been more difficult to obtain due to source fragmentation (cf. European air transport and ATM data) and lack of usable future targets (cf. SESAR Performance Ambitions). Lessons learned in the wider context (thus) include: • Limited synchronised data availability and coherence across modes, with fragmented and missing rail data in particular, may cause significant delays to modelling: The novel approach re. integrating the air-rail layer modelling required a very high effort. • Obtaining disaggregated route-level data for the different markets and scenarios considered in the Modus analysis was a challenge as was robust parameterisation of the scenario variables in the simulation and other quantitative modelling

ID	Criteria	Satisfaction	Rationale - link to deliverables - Comments
			○ Scenarios are much easier to describe qualitatively than they are to parameterise in detailed simulation models ○ Lack of sufficient differentiation across scenarios, combined with insufficient parameterisation data, may lead to the need to drop one or more from the full simulations in a 24-month project (as for Modus and Scenario 4) ○ A country-based approach solves several problems cf. building a full European network (one can model short-haul bans within a state and focus on more available rail data) ○ Localised disruption (e.g. fixed across scenarios to one or two cities) can similarly help to focus on where better quality rail data are available • Further work and data on passenger process times within the airport are needed (and may well be available for some of the case studies elsewhere in SESAR ER4 multimodal projects) • Online, cf. physical, collaboration (both internal and external workshops) due to Covid-19 enabled higher outreach • Workshops with other ER4 multimodality projects was useful to identify synergies and exchange on multimodality topics. • Expert involvement during the entire project was very useful re. the validation of assumptions, feedback on intermediate results and insights into different mobility sectors
TRL-1.8	Do fundamental research results show contribution to the Programme strategic objectives e.g. performance ambitions identified at the ATM MP Level?	Achieved	There are different areas of both the European Air Traffic Management (ATM) Master Plan (MP) as well as the SRIA Digital European Sky to which the Modus research results contribute. *1) Achieving improved airport performance and access by implementing enhanced runway throughput capabilities; assess the enabling of 3-fold increase in ATM capacity, including the accommodation of additional flights at high traffic airports; reduced delays, increased network throughput and throughput at congested airports, including traffic growth forecast impact (ATM Master Plan)*

ID	Criteria	Satisfaction	Rationale - link to deliverables - Comments
			Modus has developed and assessed various scenarios that depict future development paths of the air and rail sector. These include different traffic growth assumptions, both for air and rail (Deliverable D3.2 and D5.2). Applying modal choice analysis across these scenarios and for selected routes within Europe provides a variation in market shares of air-rail transport and a detailed insight and discussion into what drives the change in market shares across scenarios. Furthermore, the passenger mobility modelling approach provides an insight into the door-to-door impact across different scenarios, such as the impact of a significant short-haul shift from air to rail and the impact of disruptions on the predictability of journeys (Deliverable D5.2). *(2) The future European ATM system relies on the full integration of airports as nodes into the network (ATM Master Plan), and creating a seamless passenger experience and interoperability between different transport providers will be enabled by the complete integration of airports as multimodal nodes into the ATM network (SRIA).* First, Modus provides to the strategic objectives by detailing seven distinct passenger archetypes which enhance the understanding of factors driving the passenger experience and respective decision-making regarding door-to-door journeys (Deliverable D3.2). These archetypes are assigned with different characteristics that have an influence on the assigned travel times during the different steps of the journey, for example (Deliverable 4.2 and D5.2). Second, via an extensive consultation process involving experts from different transport domains, particularly air and rail, enablers and barriers have been identified to establish airports as multimodal nodes, inter alia (Deliverable D5.2). *(3) The impact of Modus in enabling a 10% reduction in the effects flights have on the environment; reduce CO_2 emissions, increase operational efficiency for airspace users (reduced fuel burn and flight time) as well as increased mobility with a lower environmental impact (ATM Master Plan); the research activities will aim at better understanding the impact of aviation on the environment and the ways in which ATM can reduce these effects ("Work Area 1 - ATM Excellent Science and Outreach" - Sub Work Area 1.3: Environment & Meteorology for ATM)* The complementarity and substitution between air and rail has been an intensely discussed topic recently in regard to the capability to reduce transport's environmental impact or providing a seamless travel experience. The Modus approach provides a tool to assess potential impacts of a closer cooperation or substitution effects between air and rail, especially regarding the impact on the areas of capacity (e.g., door-to-door travel times), predictability of journeys, and the environment (CO_2 emissions).

ID	Criteria	Satisfaction	Rationale - link to deliverables - Comments
			(4) Increasing network resilience and the reliability and predictability of journey parameters, enhancing punctuality and passenger experience overall (SRIA); and placing increased focus on multimodal solutions will facilitate additional environmental benefits […] from alleviating congestion at and around airports by improving passenger flows (through predictability and single-ticketing), from helping access/egress to/from airports, using environmentally-friendly means […]. The Modus results provide a more detailed understanding of passenger expectations which contribute to evaluating different journey requirements and priorities along the journey. Furthermore, Modus use cases enable to analyse different aspects of the door-to-door journey in a more comprehensive way, discussed and assessed in detail in the Modus expert workshops. The integration and consultation of a large and diverse Industry Board from different transport domains yielded the identification of enablers as well as barriers for enhanced multimodal solutions potentially enhancing reliability and predictability of future journeys. First, Modus considers various passenger archetypes, their needs and requirements along the journey. This helps to better differentiate how seamless and inclusive travel options can be designed in the future. There is no 'one solution fits all', both in terms of transport infrastructure supplied and services offered, for example. The results of the Modus project show which factors will have an influence on future traveller behaviour and how changes in different factors may influence the modal decision and hence market shares, for example. *5) In terms of sustainable mobility, one of the goals is a stronger focus on multimodality. This is encompassed in the objectives that "sustainable alternatives must be made widely available now in a fully integrated and seamless multimodal mobility system" (p. 7), and that "Europe should build a high quality transport network with high-speed rail services on short-haul distances and with clean aviation services improving coverage of long-haul routes" (p. 7). (European Commission Sustainable and Smart Mobility Strategy in 2020).* One of the pillars enabling smart and seamless mobility is "EU-wide, integrated, multimodal information, ticketing and payment services" (p. 12). Furthermore, in order to "create a truly smart transport system, efficient capacity allocation and traffic management must also be addressed to avoid a capacity crunch and reduce CO_2 emissions" (p. 13). (European Commission Sustainable and Smart Mobility Strategy in 2020). The scenarios developed within Modus establish different levels of cooperation and substitution between air and rail transport within Europe, reflected, for example, in the form of varying traffic growth rates of these two transport sectors, or the level of short-haul air traffic being substituted by rail transport and thus serving as feeder traffic to airports. These scenarios are assessed in terms of modal market

ID	Criteria	Satisfaction	Rationale - link to deliverables - Comments
			shares, travel times or capacity impact and therefore provide valuable insight and information for the goals outlined in (5). *(6) The strategy also comprises that "mobility [is] affordable and accessible in all regions and for all passengers including those with disabilities and reduced mobility", and that a "multimodal framework for passenger rights [is pursued] that is simplified, more consistent and harmonised" (p. 17) (European Commission Sustainable and Smart Mobility Strategy in 2020)* First, Modus considers various passenger archetypes, their needs and requirements along the journey. This helps to better differentiate how seamless and inclusive travel options can be designed in the future. There is no 'one solution fits all', both in terms of transport infrastructure supplied and services offered, for example. The results of the Modus project show which factors will have an influence on future traveller behaviour and how changes in different factors may influence the modal decision and hence market shares, for example. Second, the Modus project results also assess a multitude of key performance and connectivity indicators from various transport domains which enable the comprehensive assessment of multimodal solutions and the impact on both passengers and transport providers. This is important since comparing different mobility solutions or concepts in terms of their impact on the transport system can help design policies or steer investment. *(7) Airports are envisaged to become multimodal connectivity hubs that facilitate seamless transfer between modes. In addition to this, the vision states that a "legal framework for seamless door-to-door journeys [needs to be] in place addressing passenger rights in a multimodal transport environment as well as enabling personalised travel and reconfiguration of journeys by exchange of contextual journey information in a GDPR-compliant way" (p. 58). (European Flightpath 2050, and the new aviation vision Fly the Green Deal)* Aspects relating to passenger rights, data sharing and privacy, related liability issues as well as coherence across transport modes, especially air and rail, have been discussed and assessed during two Modus workshops with multiple experts from different transport domains. The results and consolidation of these assessments are publicly available and provide insights as to the different perspectives but also synergies which have to be further built upon.

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			(8) Focus shall be placed on a customer-centric transport system, the design and implementation of an integrated, intermodal transport system, and emphasises that it is important to develop capabilities to evaluate mobility concepts, infrastructure and performance. (ACARE SRIA) The distinct passenger archetypes developed and assessed within Modus contribute to a better understanding of what a customer-centric mobility system may look like. Not all travellers' requirements along the door-to-door journey are the same but may different in regard to trip duration, length of stay, household income, age, gender, or travel group size. Modus differentiates passenger profiles along these parameters, and a modal choice analysis provides further insight regard the impact of various factors on the travel choice regarding air and rail and the impact on overall demand.
TRL-1.9	Have stakeholders been identified, consulted and involved in the assessment of the results? Has their feedback been documented in project deliverables? Have stakeholders shown their interest on the proposed solution?	Achieved	Yes, as documented on the Modus website and in Deliverables D3.1 and D5.2 regarding the Modus Industry Board and other external experts. Different stakeholders have been involved in the form of expert interviews, workshops and bilateral consultation as well as during conference presentation or participation of the Modus consortium in relevant events. Furthermore, there has been a detailed exchange with other ER4 multimodality projects in regard to traveller archetypes, scenarios and overall results of the different projects along the entire duration of the Modus project. • Establishment of Modus Industry Board • Expert survey for identification and validation of Modus assumptions and results • Expert workshop 1: Future drivers and multimodality • Expert workshop 2: Scenarios, use cases and city archetypes • Expert interviews re. air-rail barriers and opportunities
TRL-1.10	Have initial scientific observations been communicated and disseminated (e.g. technical reports/journals/conference papers)?	Achieved	Yes, as highlighted in the Communication, Dissemination and Exploitation Plan, and the overview provided in the final project results report (D5.2) and final dissemination report (D6.2), the Modus consortium pursued a comprehensive strategy in regard to communication and dissemination activities. The goal has been to engage as well as communicate and disseminate results to a multitude of stakeholders, including industry, academia and the different transportation stakeholders. Results and insights were therefore shared in conferences, workshops, publications, expert workshops and

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			newsletters. These activities are highlighted on the Modus website as well as Modus social media channels.
TRL-1.11	Are recommendations for further scientific research documented?	Achieved	The results of the Modus project have shown that there are some essential requirements and key enablers to foster multimodality in Europe. Among all these recommendations, we believe that it is essential to consider different scenarios, use cases and developments in long-term planning, also given uncertain economic, social and even pandemic-related developments in Europe. Scenarios, such as those presented in this documents, can help to make sense of the future and to structure decision- and policy making. They also provide initial insights of joint air-rail mobility and the impact on key performance areas such as capacity, predictability or the environment. A truly multimodal mobility system within Europe has to meet certain requirements, inter alia: • Close cooperation between air and rail mobility providers to ensure a seamless door-to-door journey for travellers (including data availability and sharing, integration of privacy requirements). • Holistic approach to meet the climate goals and comprehensive assessment of different modes. • Integration of remote regions, their connectivity and accessibility, and taking into account diverse traveller needs. • Emergence of new actors in the mobility market (also outside the transport sector) as well as business models. • Setup of a regulatory framework for better cooperation. • Adaption towards local requirements and market needs, e.g. taking into account different network structures • A fruitful collaboration between industry and research / science / academia to use the skills and inputs from both worlds • A shift towards true multimodality is a change process and needs a mind-set shift at the stakeholders side, too (e.g., align vocabulary)

ID	Criteria	Satisfaction	Rationale - link to deliverables - Comments
			Moving towards true multimodality, the following key enablers have to be considered: • Legislation and a regulatory framework are required that foster cooperation across modes and across national borders. • Design of measures, policies and incentives which are tailored to specific regions and routes. • Transparency of all and external costs of transport modes in order for policy makers and travellers to make informed decisions. • Establishing smart travel includes data availability and sharing, the avoidance of disruptions, and/or the dynamic rescheduling of journeys. • The power of data and platformatisation (also given stronger investments in innovative ideas) to develop a true D2D travel application for travellers • Infrastructure investments to enable an enhanced integration of different modes along the travel chain

4 Conclusion and Lessons Learned

4.1 Conclusions

The main objective of the Modus project was the focus on modelling and assessing the role of air transport in an integrated, multimodal transport system, with a focus on joint air-rail mobility. In particular, a modelling approach for the assessment of seamless, door-to-door multimodality and the passenger experience in Europe has been developed. It was applied to evaluate the impact of an improved, joint air-rail transport system, characterising the contribution of air traffic management (ATM) and air transport to the improvement of travellers' multimodal journeys.

Demand and supply drivers | Traveller archetypes

- Drivers for multimodal transport in Europe
- Development and analysis of future traveller archetypes, behaviour and requirements
- Evaluation of modal choice behaviour and air-rail market shares

Gaps, barriers and recommendations

- Interactive stakeholder engagement from different mobility domains, esp. air and rail
- Identification and evaluation of enablers and barriers for multimodal transport

Future multimodal scenarios

- Identification and development of various future pathways for future European mobility
- Addressing key aspects contributing to achieving seamless, climate-neutral mobility in Europe

Passenger mobility modelling and performance indicators

- Data-driven, integrated air-rail modelling, considering passenger door-to-door itineraries.
- Assessment across different scenarios regarding varying impacts on capacity, predictability, environment

Re. Objective "(1) <u>Multimodal door-to-door mobility</u>: Understanding the potential contribution of ATM and air transport to improve passengers' multimodal journeys and how this translates into an enhanced performance of the overall transport system."

In terms of understanding multimodal door-to-door mobility, a main part of the Modus project has been the identification of future drivers of supply of and demand for multimodal mobility. A wide variety of factors has been assessed showing the complexity and interlinkages across social, political, environmental, technological, and economic decision-making factors. This multitude of influences evokes different travel behaviour as well as infrastructure investment and development. In the Modus project, these potential development paths have been captured in the form of four future multimodal scenarios, including the pre-pandemic recovery (the baseline case), a European short-haul shift, strong growth with technological support, and the move towards a more decentralised mobility within Europe. These scenarios and the qualitative description along a large variety of parameters provide a comprehensive overview as well as the baseline for the derivation of implications for transport providers or policy makers, for example.

A subset of the scenario parameters, such as air and rail traffic growth, or price developments have been quantified in order to be implemented in the passenger modal choice and passenger mobility models. The parametrisation as well as the related data acquisition have been a challenging task, a large number of data sources as well as experts from different transport domains have been consulted for the identification and validation of scenario parameters. The results and overview of the Modus provide a comprehensive basis for future research and assessment.

The application of the modal choice analysis across a subset of these scenarios as well as to different routes within Europe shows that there is no general statement to be made regarding an air-rail joint mobility strategy. From the analysis, it can be seen that there are routes with already a well-established HSR connection and a high share of rail traffic. The potential of extending rail capacities in the future may therefore have a strong impact on air-rail market shares, and which sector may take up higher portions of additional demand in the future. These considerations have to be taken into account when making investment in infrastructure and/or designing mobility products and services. Applying the Modus modal choice analysis to different countries and city connections in Europe shows that the own-price elasticity of demand differs in regard to Spain, France and Germany. A main conclusion can be drawn from the model and its results across all countries: A small increase in the ticket price of one mode may lead to a significant shift of market share to the other mode. In general, for a 1% increase in the average level of fares, the average demand decreases by about 5% in France, 9% in Germany and 11% in Spain.

In addition to this, seven future traveller archetypes were developed showing the diverse mobility needs and requirements among travellers. A true multimodal transport system is called up to offer mobility services that are tailored towards such personal needs, including differences in trip purpose, value of time or the level of environmental awareness, for example. Hence, traveller archetypes vary according to their willingness to pay for travel products and services along their journey, or the requirements or process times along each step of the door-to-door journey. These elements are also reflected in the multimodal performance assessment.

Re. Objective "(2) Multimodal performance assessment: 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."

The multimodal performance assessment in the Modus project built on and extended two well-established simulation models, the Mercury passenger mobility model and the R-NEST tool. Within the course of the project, both models have been advanced to take into account rail travel as well as door-to-door journeys in order to calculate according metrics. Furthermore, the holistic approach in Modus, integrating air and rail in the wider, door-to-door context, prompted the development of city archetypes, rather than focusing on airports or railway stations per se. A city archetype denotes a specific combination of airport and railway connections and allowed us to generalise the modelling based on the construction of typical urban travel infrastructure. This impacts the modelling at two levels. Firstly, it allows, holistically, the consideration of movements between 'Paris' and 'London' and the future of such flows, rather than being tied to specific constraints at particular airports, for example. Secondly, it allows the construction of urban mobility models relating, for example, to airport and railway station access and egress, with generic travel time distributions per archetype. Furthermore, various stages of the air passenger journey from door to door have been defined, both for rail and air passengers.

In order to assess the multimodal performance across the different scenarios, a number of experiments have been designed to evaluate the impact on key (multimodal) performance indicators, including door-to-door travel times (KPA Capacity), average flight waiting times (KPA Predictability), flight delays, or the gate-to-gate CO_2 emissions (KPA Environment). Each of the experiments has been run with and without a disruption, thus showing the impact on the different mobility metrics. Due to the scope of the project and available resources, detailed experiments have been designed and simulated for the first three scenarios previously outlined.

Re. Objective "(3) Way forward: 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."

The results of the Modus project have shown that there are some essential requirements and key enablers to foster multimodality in Europe. Among all these recommendations, we believe that it is essential to consider different scenarios, use cases and developments in long-term planning, also given uncertain economic, social and even pandemic-related developments in Europe. Scenarios, such as those presented in this documents, can help to make sense of the future and to structure decision- and policy making.

A truly multimodal mobility system within Europe has to meet certain requirements, inter alia:

- Close cooperation between air and rail mobility providers to ensure a seamless door-to-door journey for travellers (including data availability and sharing, integration of privacy requirements).
- Holistic approach to meet the climate goals and comprehensive assessment of different modes.
- Integration of remote regions, their connectivity and accessibility, and taking into account diverse traveller needs.
- Emergence of new actors in the mobility market (also outside the transport sector) as well as business models.
- Setup of a regulatory framework for better cooperation.
- Adaption towards local requirements and market needs, e.g. taking into account different network structures
- A fruitful collaboration between industry and research / science / academia to use the skills and inputs from both worlds
- A shift towards true multimodality is a change process and needs a mind-set shift at the stakeholders side, too (e.g., align vocabulary)

Moving towards true multimodality, the following key enablers have to be considered:

- Legislation and a regulatory framework are required that foster cooperation across modes and across national borders.
- Design of measures, policies and incentives which are tailored to specific regions and routes.
- Transparency of all and external costs of transport modes in order for policy makers and travellers to make informed decisions.
- Establishing smart travel includes data availability and sharing, the avoidance of disruptions, and/or the dynamic rescheduling of journeys.

- The power of data and platformatisation (also given stronger investments in innovative ideas) to develop a true D2D travel application for travellers
- Infrastructure investments to enable an enhanced integration of different modes along the travel chain

Along these three high-level objectives, Modus thus achieved to provide a better and more detailed understanding of travellers' requirements along the door-to-door journey, translating the multitude of influencing factors into comprehensive future multimodal scenarios. This is also reflected in the depiction and assessment of connections and dependence between air and rail in particular, as simulated in detail in the multimodal performance assessment for door-to-door journeys.

4.2 Lessons Learned

A key challenge for the project has been the robust parameterisation of the scenario variables in the simulation and other quantitative modelling. The multimodal focus in particular, for air and rail joint mobility, requires coherent datasets for supply and demand modelling. The availability of this type of data is different for the various transport modes and therefore enormous extra effort had to be invested in data acquisition and processing to obtain disaggregated route-level data for the different markets and scenarios considered in the Modus analysis. This has also required some data filling and various assumptions to be discussed and agreed across the team, over several months, particularly due to missing future rail data (although missing current rail data was also a very great challenge). Overall, rail data have been more difficult to obtain due to source fragmentation (cf. European air transport and ATM data) and lack of usable future targets (cf. SESAR Performance Ambitions). Lessons learned in the wider context (thus) include:

Limited synchronised data availability and coherence across modes, with fragmented and missing rail data in particular, may cause significant delays to modelling:

- The novel approach re. integrating the air-rail layer modelling required a very high effort.

Obtaining disaggregated route-level data for the different markets and scenarios considered in the Modus analysis was a challenge as was robust parameterisation of the scenario variables in the simulation and other quantitative modelling

- Scenarios are much easier to describe qualitatively than they are to parameterise in detailed simulation models
- Lack of sufficient differentiation across scenarios, combined with insufficient parameterisation data, may lead to the need to drop one or more from the full simulations in a 24-month project (as for Modus and Scenario 4)
- A country-based approach solves several problems cf. building a full European network (one can model short-haul bans within a state and focus on more available rail data)
- Localised disruption (e.g. fixed across scenarios to one or two cities) can similarly help to focus on where better quality rail data are available

Further work and data on passenger process times within the airport are needed (and may well be available for some of the case studies elsewhere in SESAR ER4 multimodal projects)

From the beginning of the project, the Modus consortium placed high importance on the integration, consultation of and exchange with multimodal experts from different domains. This approach was aimed at gathering input for the different tasks within the project, validating project results along the way, and discussing the way forward for European multimodality. In particular, the lessons learned in this regard have been:

- Online, cf. physical, collaboration (both internal and external workshops) due to Covid-19 enabled higher outreach.
- Workshops with other ER4 multimodality projects were useful to identify synergies and exchange on multimodality topics.
- Expert involvement during the entire project was very useful re. the validation of assumptions, feedback on intermediate results and insights into different mobility sectors

4.3 Plan for next R&D phase (Next steps)

In line with the initial Modus objectives, and the achievements of the project outlined above, there are multiple aspects which yields high research potential for the next R&D phase. Improving and implementing multimodal solutions are key enablers for seamless, emission-free journeys of the future. Therefore, it is essential to have tools and approaches available which enable a comprehensive assessment of new multimodal solutions and their impact on different mobility stakeholders.

Within Modus, a range of key performance indicators, responding to high-level key performance areas (KPAs), have been identified to represent well the context of multimodal air-rail mobility. These performance and connectivity indicators have been assessed qualitatively and quantitatively within Modus. Due to the project scope and duration, a set of indicators has been selected to be analysed in detail. In the next R&D phase, the list of indicators integrated in a **multimodal performance framework** can be extended and subject to further analysis and assessment of multimodal solutions. Understanding the impact of a conceptual implementation of new mobility solutions in terms of e.g. flexibility and predictability for passengers, operators' business models (revenue streams and costs), or environmental impact can advance the analysis within the Modus project. We anticipate the integration of these models with a multimodal performance framework, and thus building solutions at higher technology readiness levels with a specific focus at the strategic (e.g. scheduling) and tactical (e.g. disruption) phases. And the challenges which have been overcome within Modus, not least the extrapolation of supply-side delivery in the air and rail sectors to future scenarios, under given economic and other exogenous contexts, will strengthen and inform such future research.

In regard to the multimodal passenger mobility modelling, Modus developed city archetypes which can be advanced by identifying and applying **regional archetypes**, and the impact and implementation of multimodal solutions across these. This can provide further insight for policy makers and transport providers in designing new multimodal solutions for different European regions. The modelling in Modus is anticipated to form the basis of a multimodal evaluation tool, critically capable of quantifying new policy impacts, which are often implemented in the absence of such an assessment.

Next research steps, may also include the further development of the **passenger mobility model to take into account the rail layer as part of intramodality**, and thus to assess and evaluate multimodal door-to-door journeys in more detail. This also includes the **enlargement of the common air-rail database** with additional data on multimodal journeys collected directly from operators and/or by dedicated passenger surveys. This will also allow for the **enhanced analysis of passenger mobility behaviour** to assess future modal choices.

5 CDE Activities and Project References

5.1 Communication, Dissemination and Exploitation Activities

A detailed report on all Modus activities relating to Communication, Dissemination and Exploitation is provided in Deliverable D6.2 (Final Dissemination Report).

5.1.1 Communication activities

A wide range of channels has been used, and activities were undertaken, addressing different target groups such as the aviation and railway communities, the scientific community or policymakers.

- A coherent visual identity including the project logo, templates and poster;
- Developing an online presence in the form of project website, social media channels (Twitter https://twitter.com/modus_project and LinkedIn: https://www.linkedin.com/company/moduseuproject/);
- Periodic Enews letters have been published through the usual channels of the different members of the consortium involved in the project all along the project;
- Internal communication has been assured by a managing information system, mailing list and regular meetings;
- External communication has been based on a list of key messages about Modus to be shared with the target audiences.

Modus also set up the project's visual identity at the beginning of the project, including a project logo, project flyer, and a project communication kit for all partners.

A dedicated website was set up at the beginning of the project using the already set graphic identity. The URL of the website is Modus-project.eu. The website is publicly accessible, mobile friendly and is linked to Google Analytics to keep track of visitors. The public website contains the following pages:

Homepage: this page provides an overview of the project alongside a fact and figures section displaying the main facts about the project (budget, coordinator, timeline etc.). The page also contains a News feed and integrates the social media of the project;

Overview: on this page, visitors can find the most information about the project including the context and the objective of the project, as well as the methodology of its implementation;

Consortium: this page includes the logos, descriptions and links of all project partner websites;

Publications: all public deliverables of the project have been displayed in this section and are available for download once submitted and validated, as well as, events presentations, posters and brochure;

News and events: here all past and upcoming events are displayed. Newsletters and press releases are available in this section as well to keep visitors up to date with the developments and activities of the Modus project;

Contact: this page consists of a contact form that is automatically directed to the project coordinator and the dissemination WP leader.

The footer displays the EU flag and the SESAR JU logo, and the Grant Agreement number. It also includes the Modus website cookies policy.

The structure of the public website is adapted and be amended to suit the project and partner's requirements as delivery occurs. The website will remain online after the end of the project for at least three years.

Google Analytics and Google's tools for webmasters were used to analyse the RSS feeds and web page use. From June 2020 to November 2022, the website was visited by 7873 visitors (3582 returning users and 4291 new users) for 6430 sessions (see below).

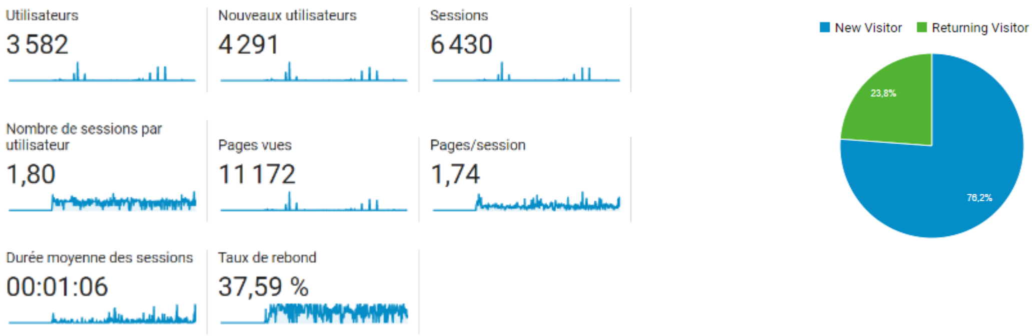

Figure 11: Number of visitors of Modus website

The communication of the project also benefited from a strong and efficient presence in social media. Twitter and LinkedIn were the two preferred media for this purpose.

A Modus Twitter and LinkedIn accounts were launched at the beginning of the project. It has been used to convey messages from the Modus project, from the SESAR JU, the partners of the project and from actors of the aviation, railways and from the transportation sector regarding multimodality. To ensure a strong synergy Modus' Twitter and LinkedIn accounts did regularly tag the SESAR JU, repost and liked SESAR JU Twitter content with a special focus on other SESAR multimodal projects' contents.

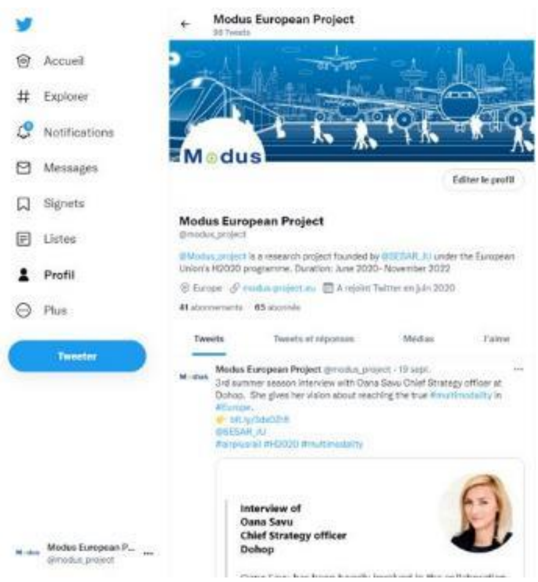

Figure 12: Tweet example

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Between June 2020 and September 2022: 101 tweets, 20 994 Tweets impressions, 20 mentions, 66 followers.

Figure 13: Number of followers on Twitter Modus

Since the beginning of the project, 30 posts have been done on Modus LinkedIn.

Total number of visitors (between September 2021 and November 2022): 675
Total number of followers: 185 followers

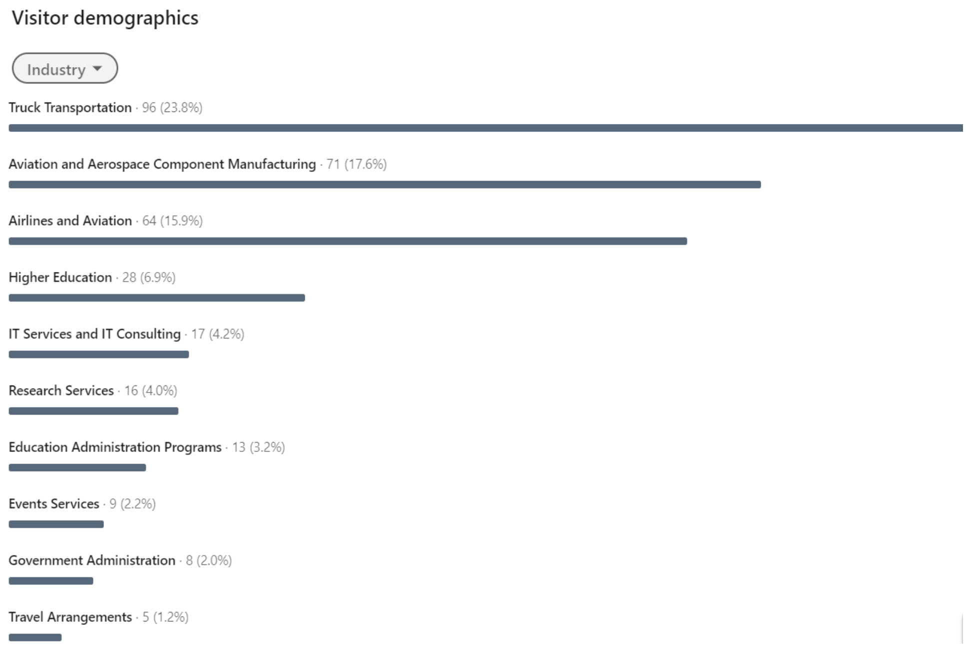

Figure 12: Visitors demographic on Modus LinkedIn

Most of visitors came from transportation (especially rail and aviation), research (7.9%), business development (9.2%), and project management (10.4 %).

In addition to the Twitter account, LinkedIn has been used as another social media medium to spread the word about Modus by using the already existing networks of the project partners.

LinkedIn is a platform most often used for business-to-business communication and to create a professional image for both individuals and corporations. Modus has opted for a company page https://www.linkedin.com/company/moduseuproject (Modus EU). LinkedIn Company pages cannot follow other users. Thus, the success of the Modus EU page relied with the active promotion of the page by consortium partners. Many of the consortium partners use LinkedIn for their own personal professional communication and as such followed the Modus EU page as well as liked and shared content posted by Modus. Posts from Modus focused on published results as well as promoting workshops.

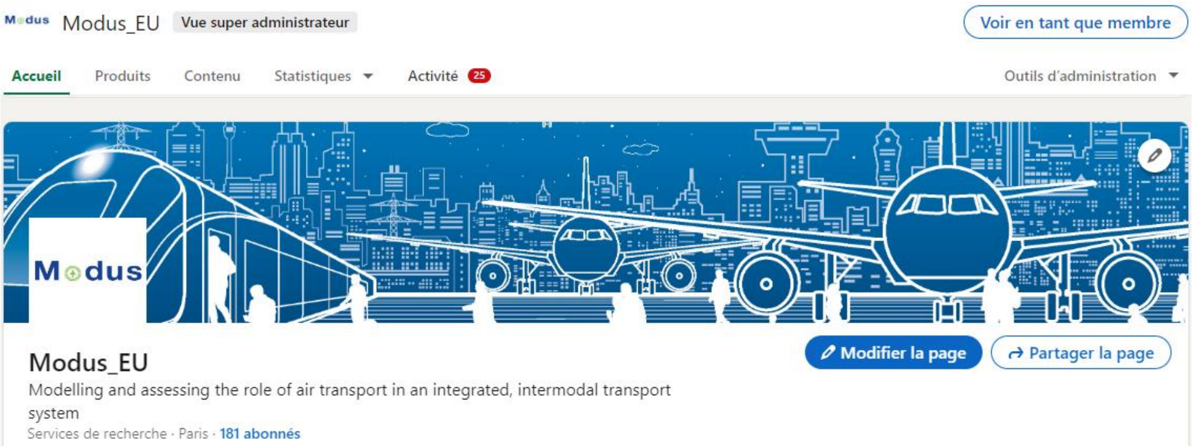

Figure 14: LinkedIn administrator page

These two social media have been used, all along the project life, to disseminate Modus results and to enhance the visibility of SESAR JU to the largest audience possible, in the aviation, railways and in the transport sector in general. They benefited from the large presence of SJU and of the project partners in the social media.

Partners posting to social media sites used the #Modus_EU hashtag so that these posts could be easily identified and relayed to other social media platforms and our project website.

Regular information has been published through the usual channels of the different members of the consortium involved in the project, such as:

- UIC e-News (articles were published in the UIC electronic letter for each Modus event, like Kick-off, deliverables and workshops), as well as for any important result achieved by the project partners. The UIC e-News is sent to more than 4000 addresses in the railway community all around the world. An article entitled "Official launch of the European Project Modus (modelling and assessing the role of air transport in an integrated, intermodal transport system) on 2 June 2020" was published in the UIC e-News #696 of 16 June 2020 (https://uic.org/com/enews/nr/696/article/official-launch-of-the-european-project-modus-modeling-and-assessing-the-role). This article and the following are made available on the project website;

- SESAR JU channels. Annika Paul, Modus coordinator from Bauhaus Luftfahrt, interview has been published on the SESAR JU website (https://www.sesarju.eu/index.php/news/flying-multimodal-way);
- Existing communication and dissemination channels of the partners involved in Modus (such as Skyway Newsletter) have also been used. These include (electronic) newsletters, websites of the project partners and partner related communication or working events.

The external communication focused on informing about and promoting the Modus project and its results to the target audience. The members promoted Modus actions and its results by providing targeted information to multiple audiences in a strategic and effective manner.

The consortium agreed on the following text about Modus that every partner can use to introduce the project. This text is supposed to be understandable by the general public and decision makers.

About Modus:

Slogan: *Modelling and assessing the role of air transport in an integrated, intermodal transport system*

Description: 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 optimisation and alignment of intermodal 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.

The main objective of the project is the analysis of the performance of the overall transport system by considering the entire door-to-door journey holistically and assessing the role of air transport within an integrated, intermodal approach.

For this purpose, Modus identifies and assesses (future) drivers for passenger demand and supply of mobility in terms of their impact on passenger mode 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+.

The following are some of the key messages about Modus shared with the target audiences:

- The project shall contribute to better integrate and connect ATM and air transportation with other modalities.

- The project shall contribute to improve the passenger experience during door-to-door journeys, including a better understanding of customer, market and societal expectations and opportunities, leading to a customer-centric transport system.

- The contribution to the development of capabilities to evaluate mobility concepts, infrastructure and performance.

In promoting activities, members used:

The EU emblem (no need for prior approval from the SJU), downloadable from here: https://europa.eu/european-union/about-eu/symbols/flag_en

The "Supported by SESAR Joint Undertaking" logo, downloadable from here: SESAR Joint Undertaking | Use of SESAR Logos (sesarju.eu)

Reference to the grant funding from Horizon 2020: This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 891166.

Table 12: Indicators to Measure Success for each Communication Channel

Communication Channels	Key Performance Indicators	Target Value	Real Value
Project website	Total visits to project's website	5000 per year	7873
Social media	Number of post views and number of followers on Twitter, LinkedIn, and ResearchGate	20 contacts per partner (140)	185 followers LinkedIn + 66 followers Twitter
Newsletter	Number of publications	1 per year	1 + 22 News items on the Modus Website
Promotional material	Number of flyers and brochures distributed	200 per year	Teaser, Youtube, posters were published
UIC Channels	UIC E-Newsletter	4500 per newsletter 3500 media contacts per release	22 articles in UIC E-Newsletter

5.1.2 Dissemination activities

The Dissemination Plan of Modus focused on describing and ensuring that results will be available for others to use at any time and as soon the action has results.

Modus dissemination objectives:

- To disseminate project development and results to stakeholders and external actors;
- To implement and update dissemination material to ensure continuous outreach of the project outcomes;
- To organise and participate in key events to ensure cooperation and establish liaisons with related projects and initiatives;

- To foster knowledge among all project partners and the SESAR JU ecosystem (especially with SESAR projects related to multimodality) to maximise the impact of EU-funded research;

- To mobilise leading experts from different business and industry sectors to participate and contribute to workshops;

- To publish the scientific and practical results (where possible) during the whole project and especially during the dissemination phase and beyond.

A wide range of activities has been undertaken to reach these objectives:

- Participation in and organisation of dedicated events to increase an effective dissemination of the project outcomes to target stakeholders;
- Publishing of scientific and technical papers of the project findings;
- Motivation of project partners to engage their networks.

Modus partners established an Industry Board (IB) in the first months of the project. The board members and other experts have contributed to the assessment of results obtained during different stages of the course of the Modus project.

This board included:

- Members of the aviation, railway and transportation industry, and
- Experts from different air and railway scientific institutions

The IB has been an input across the entire Modus project, and was thus involved in the identification of future demand and supply scenarios, the assessment of passenger mobility modelling, and the identification of gaps and barriers in regard to improving the performance of the overall transport system. The involvement of IB members and other experts contributing relevant expertise to a particular topic was considered essential during different stages of the project. Industry Board members together with other experts have been solicited in a questionnaire and in two workshops as well as expert interviews to collect their views on drivers influencing the demand and supply within the future European transport system, and on the future air transport with air-rail complementarity aspects.

All partners were active in the promotion and dissemination, by joining major events and conferences and presenting objectives, results and achievements of the project. These are outlined in Section 5.3.

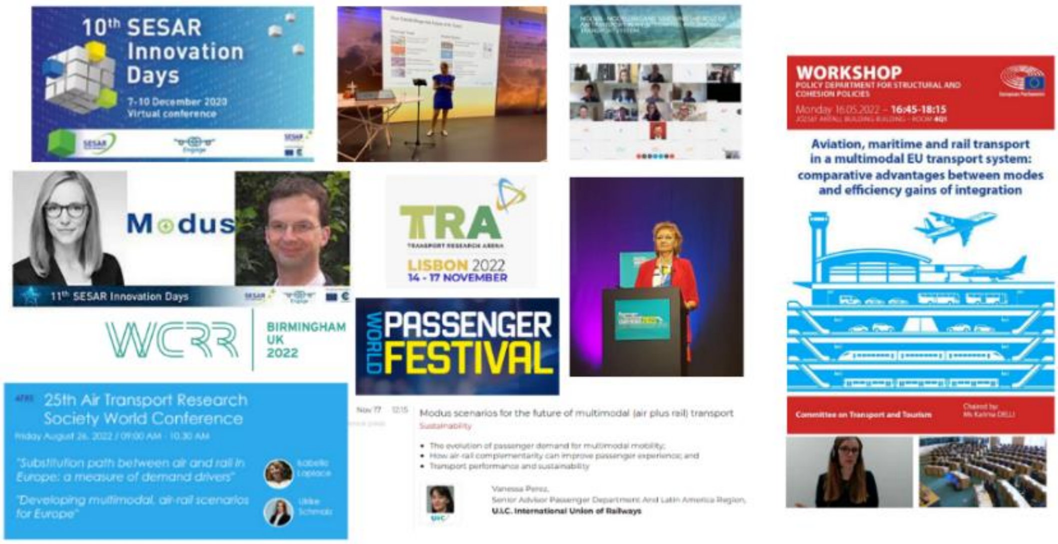

Figure 15: Modus participation in external events

Modus worked closely with complementary projects and disseminated the outcomes in particular to the Europe's Rail JU, as the Modus outcomes are particularly relevant for the Innovation Programme 4 "IT Solutions for Attractive Railway Services", and the SJU.

Some of our partners were already involved as partners or coordinators in other on-going projects. Furthermore, Modus has participated in the workshops on multimodality organised by SESAR on 29 September 2020, 5 February 2021, 16 November 2021, ER4 multimodality with the objective to inform on the project and liaise with ongoing projects on similar or related topics and (when possible) promote joint activities/events.

Link to other projects and networks examples:

Project/Networks/Publications	Synergies/Cooperation/Exchange
CAMERA (EU-H2020) 2017-2021	Within the CAMERA several European transport high-level strategies are analysed and key performance areas as well as indicators are identified; these are assessed in terms of how well the current research landscape is addressing these. Both the strategies analysed here as well as the identified gaps and barriers in regard to future research needs provided valuable input for Modus. Especially WP5 focuses on the development of various use cases that foster the achievement of EU high-level transport strategies.
DATASET2050 (EU-H2020) 2014-2017	The project provided various very good publications on demand and supply drivers, passenger archetypes, or door-to-door travel metrics; especially the drivers provide a sounds basis to be further developed and extended within Modus WP3 as well as the extension of passenger archetypes, which are applied in WP3 and WP4 of Modus.
ACARE WG1 ongoing	The ACARE working group 1 provided an excellent platform to share and discuss Modus (interim) results, obtain feedback from various experts, and to foster developments towards meeting EU

	high-level transport goals and necessary steps which are being identified within Modus; the ACARE WG1 members participate in the Modus expert survey conducted online.
SESAR JU ER4 projects (2020-2022) • TRANSIT • IMHOTEP • X-TEAM D2D • SYN-AIR	Within the SESAR JU intermodality area, there are five projects, including Modus which exhibit a high level of collaboration potential and realising exchange as well as synergies, with all of these projects focusing in general on an intermodal transport system with air transport as an essential part, and the passenger door-to-door journey. Modus consortium participated in the workshops between all projects to present the objectives of each and highlighting high-level synergies. Based on the initially identified commonalities, the projects agreed to exchange on a regular basis on the following topics (inter alia), meetings (online) were scheduled accordingly: • Development and assumptions regarding use cases (first meeting in October 2020) • Passenger profiles and scenarios • Used data sources and availability • Other topics identified along the course of the different projects Modus invited the project consortium of the other four projects to its Workshops discussing and assessing the drivers for future mobility supply and demand. Furthermore, there have been bilateral exchanges between Modus and projects on identified topics, i.e. where there might be exchange of knowledge possible. During TRA conference (Nov. 2022) SESAR Multimodality projects joined forces to highlight how to overcome barriers to data sharing and enhance multimodal door-to-door seamless transport Modus also contributed to the SESAR publication published on November 2022: *Exploring the boundaries of air traffic management*, including the Modus project.
Engage KTN (SESAR-EU-H2020) 2018-2022	The Engage network and platform provided an opportunity for the Modus project to engage in helping to align exploratory and industrial research, by providing research results, fostering discussions and exchanging with experts from different areas within and outside of SESAR. It also helped to improve connectivity between projects, especially ER and IR, and to improve researcher visibility and communications.

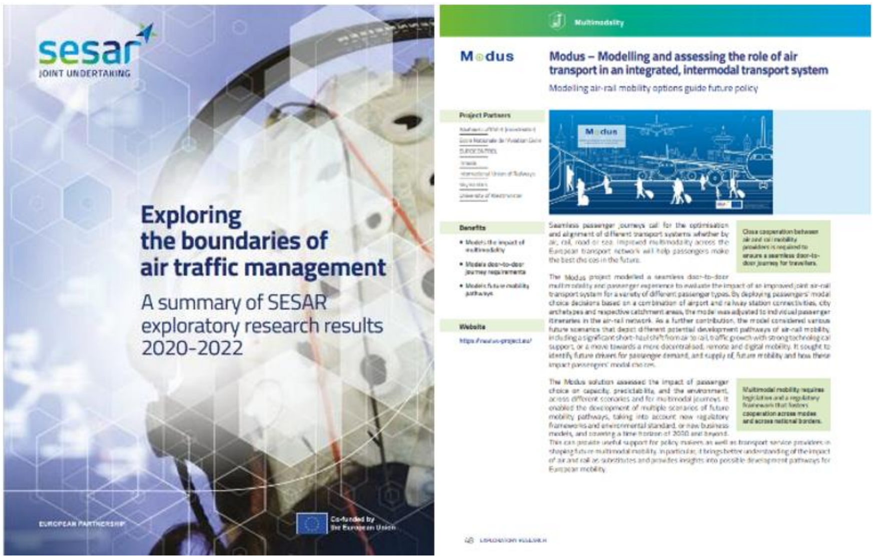

Figure 16: SESAR publication *Exploring the boundaries of air traffic management*, including Modus

The project produced two electronic newsletters. The newsletters were released in 2021 and 2022. They provided up-to-date information on the status and achievements of the project. INX and SKY have been in charge of one newsletter each, with the contribution of all partners concerning the content of these newsletters.

In order to ensure that the widest audience possible is reached, each partner used its own mailing list. The newsletters have also been uploaded on the project webpage.

Additionally, the consortium partners have used their own networks to widely disseminate the results of the project.

The first e-newsletter was sent in December 2021 by INX. The average on Innaxis opened was 13% and 103 clicks on the links.

Email Performance

See how your emails are doing with your audience. Compare your results to the industry average.

Sent	Open Rate	Click Rate
2244	19.5%	1.2%

Opens	376	Clicks	24
Sent	2244	Did Not Open	1554
Bounces	314	Unsubscribed	7
Successful Deliveries	1930	Spam Reports	0
Desktop Open Percentage	90.5%	Mobile Open Percentage	9.5%

Figure 17: Email performance of the first newsletter

Once all the deliverables will be published, a final Modus brochure following Modus graphic elements will present the key results of the project, as well as recommendations for the different target groups.

In addition to having the general information about Modus, it will provide more detailed information about the project´s results acting as a means of exploitation.

This brochure will be disseminated through targeted mailing with target group members using a final Newsletter and a press release. A pdf version will be available on the project website. Social media have been used to promote this document.

The final dissemination workshop to be held at the beginning of 2023 will be the occasion to disseminate the brochure with the final results.

Figure 18: Modus poster with Modus graphic elements

Table 13: Indicators to Measure Success for each Dissemination Channel

Dissemination Channels	Key Performance Indicators	Target value	Real value
Creation of an Industry Board	Number of Workshops	3 workshops	2 workshops
Conferences	Number of presentations	5 per year	22
Scientific publications	Number of publications	2 per year	4
Project website	Total visits to project's website	5000 per year	7873
Social media	Number of post views and number of followers on Twitter, LinkedIn, and ResearchGate	20 contacts per partner (140)	185 followers LinkedIn + 66 followers Twitter
Newsletter	Number of publications	1 per year	2 + 23 News Modus Website
Promotional material	Number of flyers and brochures distributed	200 per year	Teaser, Youtube, posters were published
UIC Channels	UIC E-Newsletter	4500 per newsletter	Press Release published at the end of the project to disseminate last results

	Press releases issued in 3 languages: English, French, German)	3500 media contacts per release	

5.1.3 Exploitation activities

The exploitation activities aimed at enabling different stakeholders and Modus project partners to make concrete use of research results. The target audience includes both user groups outside of the Modus project, and Modus consortium partners.

Target groups	Topics	Means
Industry (airports, airlines, railway operators)	Insights into traveller archetypes, travel behaviour and modal choice decision making; Passenger mobility modelling: schedule design and disruption impact	Leveraging Modus results via: Publications on industry stakeholder platforms; participation in relevant workshops and conferences. Scientific findings have been translated into potential courses of action regarding the implementation of an optimised European transport system, and the role of different transport service providers. The results have been provided in the form of reports (deliverables) as well as scientific publications which are accessible and applicable for operators within the aviation and rail communities, and beyond. This includes the assessment and discussion of how key performance indicators from the ATM sector are being affected.
Scientific community	Modelling approaches Extension of Mercury G2G model and RNEST tool integrating rail layer; Enhancement of modal choice analysis Travel demand and supply analysis Development and modelling application of traveller archetypes	Scientific journal publications; participation in conferences; leveraging results in teaching (novelties in modelling); exchange on modelling and validation of further modelling extensions.

	Identification and assessment of future drivers for mobility supply and demand Quantification of scenario parameters and integration into passenger mobility modelling	
Policy makers	Implications of joint air-rail mobility and incentives for different mobility providers. Topic contributions may refer to, inter alia, the establishment of multimodal cooperation with respect to specific city archetypes or European regions, insights regarding disruption management and the implications for service providers, assessment of KPAs (especially Capacity, Predictability, Environment), travel behaviour assessment and implications for door-to-door journeys.	Engagement with national and EU policy makers within the scope of each partner's scientific communication and dissemination activities (e.g. ACARE; ERA; Umweltbundesamt (DE); VDI (DE); DG MOVE; EU Joint Research Centre). Policy makers have already been addressed as part of the communication and dissemination activities from an early stage of the project; e.g. in form of participating in the Modus workshops, or attending conferences with policy maker attendance (e.g., TRA conference; TRAN workshop). The results of the Modus project will be used by the consortium partners in further discussions and exchanges concerning the design of a multimodal European mobility system.

The European Commission pursues an initiative which aims to use research and innovation project results to shape policy making, "Projects for Policy (P4P)": https://ec.europa.eu/info/research-and-innovation/strategy/support-policy-making/scientific-support-eu-policies/p4p_en. In order to support the European Commission in evidence-based policy making, the Modus project results will also be highlighted to this particular initiative. In line with the objectives of P4P, Modus can contribute by:

- providing evidence for policy development and design in the area of an optimisation of in intermodal, integrated European transport system;
- highlighting gaps or barriers in current policy frameworks or approaches;
- helping to develop new opportunities and innovative activities for any area of policy-making across Europe and the world.

5.2 Project Deliverables

All publicly available Modus project deliverables can be accessed via the Modus website.

Modus (2020), Project management plan (PMP), Deliverable D1.1, Edition 01.10.00, 21 September 2020.

Modus (2020), Requirement 1: Humans, Deliverable D7.1, Edition 00.01.00, 30 November 2020.

Modus (2020), Requirement 2: Personal data protection, Deliverable D7.2, Edition 00.01.00, 30 November 2020.

Modus (2021), Modal choice analysis and expert assessment, Deliverable D3.1, Edition 00.01.10, 09 June 2021.

Modus (2021), Interface to modal choice, Deliverable D4.1, Edition 00.01.00, 27 July 2021.

Modus (2021), Definition of use cases, Deliverable D5.1, Edition 00.01.10, 23 September 2021.

Modus (2021), Demand and supply scenarios and performance indicators, Deliverable D3.2, Edition 00.01.10, 02 November 2021.

Modus (2022), Database structure, Deliverable D2.2, Edition 00.01.00, 03 May 2022.

Modus (2022), Communication, dissemination and exploitation plan, Deliverable D6.1, Edition 00.02.20, 17 June 2022.

Modus (2022), Data management plan (DMP), Deliverable D2.1, Edition 1.3, 26 September 2022.

Modus (2022), Mobility models description, Deliverable D4.2, Edition 00.01.00, 8 December 2022.

Modus (2022), Report on overall final project results, Edition 00.01.10, 8 December 2022.

Modus (2022), Final dissemination report, Deliverable D6.2, Edition 00.01.00, 30 November 2022.

5.3 Project Publications

Journal papers

A. Montlaur, L. Delgado, C. Trapote-Barreiram (2021) Analytical Models for CO_2 Emissions and Travel Time for Short-to-Medium-Haul Flights Considering Available Seats. Sustainability MDPI in: Sustainability, Journal 2021. https://www.mdpi.com/2071-1050/13/18/10401

Papers and presentations at events, congresses, workshops

A. Paul (2020), Greener airports operations Flying, the multimodal way! in: **SESAR JU E-Workshop**, online, November 2020.

A. Paul (2020), Modus: Modelling and Assessing the Role of Air Transport in an Integrated, Intermodal System, in: **SESAR Innovation Day 2020**, online, December 2020.

A. Paul (2021), Modus project update and expert survey in: ACARE WG1, January 2021.

A. Paul (2021), How the ATM Scientific Community can support the Multimodal Transportation System Effectiveness. in: **Agency Research Team (ART) workshop on passenger-centred mobility**, online, June 2021.

A. Cook (2021), Key Performance Indicators in: **Agency Research Team (ART) workshop on passenger-centred mobility,** online, June 2021

A. Paul (2021), Passenger travel behaviour in a future multimodal system – Insights from the Modus project, in: **UIC Customer Experience Management Platform (CEMP) Workshop**, online, June 2021.

A. Paul (2021), Modus: Modelling and Assessing the Role of Air Transport in an Integrated, Intermodal System, in: **SESAR Innovation Day 2021**, online, December 2021.

A. Paul (2022), What could future air-rail multimodal mobility look like? Insights from the Modus project; in: Presentation for the **EU Parliament Committee** on the Modus project regarding 'Aviation, maritime and rail transport in a multimodal EU transport system: comparative advantages between modes and efficiency gains of integration – PART 2: best practices in multimodal integration analysis and design', online, May 2022. https://multimedia.europarl.europa.eu/fr/webstreaming/tran-poldep-b-workshop_20220516-1645-COMMITTEE-TRAN

P. Arich, T. Bolic, I. Laplace, N. Lenoir, S. Parenty, A. Paul, C. Roucolle (2022), Substitution path between air and rail in Europe: a measure of demand drivers, in: **World Congress for Railway Research (WCRR)**, Birmingham, United Kingdom.

N. Pilon (2022), Modus Scenarios for Future of Multimodal Travel: Horizon 2040, in: **Passenger Terminal Expo**, **Paris**, June 2022.

U. Schmalz (2022), Future Technologies and Trends – Assessing Drivers of Change, in**: ILA Berlin**, June 2022,

A. Paul, U. Schmalz, I. Laplace, A. Cook, T. Bolic, V. Perez, N. Pilon (2022), Developing Multimodal, Air-Rail Scenarios for Europe (Modus project), in: **ATRS**, **Air Transport Research Society World Conference, Antwerp** + **online**, Aug. 2022.

P. Arich, T. Bolic, I. Laplace, N. Lenoir, S. Parenty, A. Paul, C. Roucolle (2022), Substitution path between air and rail in Europe: a measure of demand drivers, in: **ATRS, Antwerp,** online, August 2022.

I. Correas, A. Correas, E. Gregori (2022), Quantification Model for Local Itineraries in Urban and Peri-Urban Areas Using Open Data, in: **ETC 2022, Milan**, Sept. 2022.

A. Paul (2022), Connected mobility systems, in: Symposium Sustainable Aviation, Hamburg November 2022.

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Nov 16, 2020, Modus: Better understanding and assessing the role of air transport in an intermodal transport system

Dec 9, 2020, Modus at the SESAR Innovation Days 2020 (7-10.12.2020) Join us 10.12.2020

Dec 14, 2020, Modus Workshop "The future of multimodal transport: horizon 2040" Save the date! 19 January 2021

Feb 5, 2021, The Future of Multimodal Transport: Horizon 2040 First Modus workshop held successfully online on 19 January

Jun 21, 2021, Modus at Agency Research Team (ART) workshop on passenger-centred mobility

Jun 23, 2021, Customer Experience Management Platform (CEMP) workshop held online on 21 June

Jun 25, 2021, New deliverable now available! Modus D3.1 Modal choice analysis and expert assessment for download

Sep 27, 2021, Download the first deliverable of WP4 of the Modus project

Oct 20, 2021, Deliverable 'Definition of use cases' is published

Dec 10, 2021, European Modus project at SESAR Innovation Days 2021

Dec 16, 2021, Discover our Deliverable 3.2 'Demand and supply scenarios and performance indicators'

Jan 14, 2022, Second online Modus workshop, save the date 14 February 2022!

Jan 19, 2022, Registration 2nd Online Workshop Modus

Mar 2, 2022, The second Modus workshop was held on 14th February 2022

May 17, 2022, Modus European project presented at the European Parliament in Brussels

Jun 22, 2022, Modus at Passenger Terminal Conference (Paris)

Jul 19, 2022, An interview with Christian Steyer: How to reach true multimodality within Europe – an air + rail love story?

Jul 21, 2022, Save the Date: 25 October 2022, Paris, UIC HQ, Modus Project Final Results Conference

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5.4 Other

Grant Agreement, Number 891166 – Modus Project

Project Execution Guidelines for SESAR Exploratory Research, Edition 01.00.00, 08/02/2016

5.5 Lessons Learned CDE activities

The Modus project consortium, under the lead of the communication and dissemination manager UIC, has been very active in various communication and dissemination activities from the beginning of the project. Lessons learned from these various activities include, in addition to those outlined in Section 4.2:

- Necessity to actively engage with stakeholders from different transport domains, especially air and rail in the case of Modus, in order to gather differences, similarities and synergies across the different mobility sectors.
- High amount and diversity of stakeholders within Modus workshops was very valuable in further advancing and refining project results and assumptions.
- The shift to online events due to Covid-19 actually led to a very high participation of the offered online workshops; these workshops were initially planned as in-person events.
- Project results have been presented and discussed at various conferences, workshops and congresses; these discussions and feedback by both the scientific and industrial communities will be considered in further planned journal publications beyond the project duration, and were considered really helpful.
- Social media platforms and the project website have proven to be efficient tools to engage with the multimodal scientific community, other multimodality projects as well as industry stakeholders.

- Due to the composition of its consortium, Modus partners were able to leverage contacts and networks from both the railway and aviation communities and foster the very valuable link between these sectors.

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Appendix A

A.1 Modal choice data collection

As presented in the introduction, the study focuses on three European countries, namely Germany, Spain and France. The data collection is therefore all the more important as it was necessary to collect all the required data for the three countries in question. There are differences between the three countries in the nature of the data collected, so we will present the data by country.

Characterisation of the routes studied

We use the NUTS nomenclature developed by EUROSTAT to determine the origin and destination areas where we measure the levels of competition between transport modes and between operators. The NUTS nomenclature is a hierarchical system that divides the EU territory according to demographic thresholds and gives priority to existing administrative divisions. There are three levels of division from 1 to 3, with NUTS-3 being the finest unit with a population threshold between 150,000 and 800,000 inhabitants. We use the NUTS-3 level to define our origin-destination (OD) or route.

In our analysis, we only consider ODs where air and rail compete. Airports are considered individually in each NUTS-3, except Paris and its region (NUTS FR101). In this case, the different airports are considered as a single entity. The rail stations, given the intermediate stops and the finer mesh of the rail network, are considered as unique in each NUTS. In other words, competition is analysed between an origin and a destination and not between two transport infrastructures, because the alternatives between stations or between airports cannot always be chosen. Moreover, our model does not develop an alternative choice of infrastructure, but rather a choice of mode.

The origins and destinations are characterised by the collection of socio-economic data. These data come from EUROSTAT. Each NUTS is characterised respectively by GDP and population size in NUTS-3 and by household income and unemployment rate in NUTS-2. This characterisation makes it possible to contextualise origin-destination according to economic and social criteria.

The data referring to air transport are all derived from the same sources and the same estimation methods, if any, irrespective of the countries included in the scope of our work.

Air and rail demand and prices

Type of data	Data source
Air and rail transport supply	The database used to analyse the market shares between air and rail transport is constructed from OAG Schedule Analyzer (a database of the Official Airline Guide) which lists all daily scheduled flights in the world and MERITS, a database provided by the UIC (International Union of Railways) which compiles daily rail traffic in Europe. OAG and MERITS, respectively, contain disaggregated information on air and rail supply, such as departure date, departure and arrival time, airport/station of departure and arrival, travel time, type of equipment. These two databases are used to quantify and characterise the monthly supply of air and rail transportation on all relevant origin-destination routes.
Air travel demand	For air market demand, we use several sources to estimate the monthly number of passengers on each OD. To do so, we combine FRACS data (France Aviation Civile Services)7 , OAG, and airline annual reports to estimate the monthly number of passengers on airport pairs. Specifically, the OAG provides the type of aircraft used for each flight along with various information such as the total seat capacity and their distribution by class. This information combined with the load factor of each airline allows us to estimate the average number of passengers per OD. It should be noted that the load factors are derived from the annual results of each company for the year 2016. However, we did not always obtain the information of the domestic load factor. Therefore, when this information was not available, we chose to use the international load factor, although it is less accurate.

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Air travel prices	Air fares are all taken from the same source, IATA PaxIS (Passengers Intelligence Services), which provides average prices per kilometre for the year 2018, by class, airline and distance intervals. These average prices are weighted by the number of passengers. In order to bring the prices back to our reference year (2016) we use the monthly consumer price index for air transport, German, Spanish and French to convert 2018 euros to 2016 euros. The harmonised consumer price indices for air passenger transport per country are taken from FRED. Finally, the average price per kilometre is multiplied by the origin-destination distance indicated in OAG, which allows us to obtain the unit price per OD, class and airline.
Rail data Germany	
Prices	The price data for the German rail sector comes from a collection conducted by the professorship of travel behaviour (Dr. Moeckel) at the University of Munich. We have an average price per kilometre calculated on the basis of prices on 72 routes in 2020. We multiply the price per kilometre by the distance of each OD.
Demand	In order to estimate the demand level of the German rail operator, we have the following two indicators provided by the UIC for long distance and high speed trains: the number of trains kilometres as well as the number of passenger kilometres. From these elements we have estimated an average number of passengers per type of train (high speed and long distance).
Rail data Spain	
Prices	Renfe fare data was collected on Kaggle and is for the period between 12/04/2019 and 05/12/2020. Kaggle (available at: https://www.kaggle.com/) is a platform for data analysts to share their work and participate in various learning challenges. There are many datasets available for free, as was the case for this dataset. The initial database being very heavy and consisting of a large amount of redundant information, so we carried out several treatments in order to keep only a minimum and maximum price by type of train, class and origin-destination. Therefore, the Spanish price database contains the minimum and maximum sales prices.
Demand	The demand for the Spanish rail operator has been estimated using the same method described for Germany. In order to estimate a level of demand, we calculate the monthly number of passengers per operator by applying the average annual load factors of the rail operators (provided by the UIC) to the monthly capacity of the ODs provided per operator (collected in MERITS).
Rail data France	
Prices	Prices for SNCF, the French operator are from a price book published in March 2016 by the railway company. The prices are indicated for high-speed trains, long distance night trains and some long distance trains by origin-destination. The published prices are full fare prices per class and per OD. For some classic long-distance trains a scale is provided to calculate the price.
Demand	The demand for the Spanish rail operator has been estimated using the same method described for Germany. In order to estimate a level of demand, we calculate the monthly number of passengers per operator by applying the average annual load factors of the rail operators (provided by the UIC) to the monthly capacity of the ODs provided per operator (collected in MERITS).

A.2 High-speed rail wait times for 2040

2.How far the capacity (frequency) can raise for the High Speed traffic (you can consider the 5G) by 2040?
Regarding the traffic data, assuming that the trend continues based on the percentage increase over the previous three years before covid19
and ignoring the data for 2021 and 2022, which are affected by Corona, we get the traffic forecast as follows:
However, it is only a reference value, as communication capacity and TRAFFIC do not seem to be proportional.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
France	51.89	52.04	51.09	50.79	50.66	49.98	50.54	58.28	56.81	59.95	35.80	35.80	63.26	66.57	69.88
Germany	23.90	23.31	24.75	25.18	24.32	25.28	27.20	28.50	31.07	33.20	18.20	18.20	35.20	37.20	39.20
Spain	11.72	11.23	11.18	12.74	12.79	14.13	15.06	15.54	16.13	16.07	5.60	5.60	16.41	16.75	17.09
Italy	8.00	8.30	9.60	11.60	11.70	13.60	14.30	15.30	15.10	21.10	21.10	21.10	23.37	25.64	23.37

	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
France	73.19	76.50	79.81	83.12	86.43	89.74	93.05	96.36	99.67	102.98	106.29	109.60	112.91	116.22	119.53	122.84
Germany	41.20	43.20	45.20	47.20	49.20	51.20	53.20	55.20	57.20	59.20	61.20	63.20	65.20	67.20	69.20	71.20
Spain	16.75	17.09	17.43	17.09	17.43	17.77	17.43	17.77	18.11	17.77	18.11	18.45	18.11	18.45	18.79	18.45
Italy	25.64	27.91	30.18	27.91	30.18	32.45	34.72	32.45	34.72	36.99	39.26	36.99	39.26	41.53	43.80	41.53

The goal of this section is to obtain the updated waiting times of the trains in 2040 based on the estimations from UIC shown above.

The data given to us is referred to future capacity. In order to do our estimations, we will assume that the capacity is inversely proportional to the waiting time, so if we double the capacity *C* we halve the waiting time *W*.

$$W \propto \frac{1}{C}$$

The percentages shown above P_{YEAR} are the increase of capacity respect to a certain baseline C_0 that we don't know. They could be used to obtain the capacity of a given year with this formula:

$$C_{YEAR} = (100 + P_{YEAR}) * C_0$$

So for example the capacity in 2040 in France would be: CFRANCE2040=(100+PFRANCE2040)∗C0=(100+122.84)∗C0 (an increase of 100% means the capacity gets doubled).

Since we are only interested in the capacity of 2040 in terms of the capacity of 2019, we can obtain it by merging the following two expressions:

$$C_0 = \frac{C_{2019}}{(100 + P_{2019})}$$

$$C_0 = \frac{C_{2040}}{(100 + P_{2040})}$$

From there it follows that:

$$C_{2040} = \left(\frac{100 + P_{2040}}{100 + P_{2019}}\right) * C_{2019}$$

And for the waiting times we only need to add the inverse proportion:

$$W_{2040} = \left(\frac{100 + P_{2019}}{100 + P_{2040}}\right) * W_{2019}$$

Now we can plug the numbers:

$$W_{2040}^{FRANCE} = \left(\frac{100 + P_{2019}^{FRANCE}}{100 + P_{2040}^{FRANCE}}\right) * W_{2019}^{FRANCE} = \left(\frac{100 + 59.95}{100 + 122.84}\right) * W_{2019}^{FRANCE} \approx 0.7 * W_{2019}^{FRANCE}$$

$$W_{2040}^{GERMANY} = \left(\frac{100 + P_{2019}^{GERMANY}}{100 + P_{2040}^{GERMANY}}\right) * W_{2019}^{GERMANY} = \left(\frac{100 + 33.20}{100 + 71.20}\right) * W_{2019}^{GERMANY} \approx 0.8 * W_{2019}^{GERMANY}$$

$$W_{2040}^{SPAIN} = \left(\frac{100 + P_{2019}^{SPAIN}}{100 + P_{2040}^{SPAIN}}\right) * W_{2019}^{SPAIN} = \left(\frac{100 + 16.07}{100 + 18.45}\right) * W_{2019}^{SPAIN} \approx 1.0 * W_{2019}^{SPAIN}$$

$$W_{2040}^{ITALY} = \left(\frac{100 + P_{2019}^{ITALY}}{100 + P_{2040}^{ITALY}}\right) * W_{2019}^{ITALY} = \left(\frac{100 + 21.10}{100 + 41.53}\right) * W_{2019}^{ITALY} \approx 0.85 * W_{2019}^{ITALY}$$

We can summarize the results as follows:

Country	2040 waiting time factor	2040 waiting time formula
France	0.70	$W_{2040}^{FRANCE} \approx 0.70 * W_{2019}^{FRANCE}$
Germany	0.80	$W_{2040}^{GERMANY} \approx 0.80 * W_{2019}^{GERMANY}$
Spain	1.00	$W_{2040}^{SPAIN} \approx 1.00 * W_{2019}^{SPAIN}$
Italy	0.85	$W_{2040}^{ITALY} \approx 0.85 * W_{2019}^{ITALY}$

A.3 Acronyms and Terminology

Table 14: Acronyms and technology

Term	Definition
ATM	Air traffic management
D2D	Door-to-door
ER	Exploratory research
EU	European Union
GDP	Gross domestic product
GDPR	General Data Protection Regulation
HSR	High-speed rail

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KPI	Key performance indicator
LCC	Low-cost carrier
MaaS	Mobility as a Service
NUTS	Nomenclature of territorial units for statistics
OD	Origin-destination
R&D	Research & development
S3JU	SESAR3 Joint Undertaking (Agency of the European Commission)
SESAR	Single European Sky ATM Research Programme
UAM	Urban air mobility
UIC	International Union of Railways

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Bauhaus Luftfahrt

ENAC

UNIVERSITY OF WESTMINSTER

innaxis

UIC
INTERNATIONAL UNION
OF RAILWAYS

skymantics

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