Modus

"It is time for multimodality!"

Modus Consortium

Final Disseminatin Event | Online | 27th January 2023

EUROPEAN PARTNERSHIP

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.

Co-funded by the European Union

Housekeeping

The **workshop will be recorded**, starting now. The presentation will be made available on the Modus website.

Please **mute your microphones** during the workshop.

After each presentation there will be a **Q&A session**, please include your questions **in the chat** during the presentation.

All results presented today are available at **https://modus-project.eu/**

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Welcome

It is time for multimodality.

Modus

Call: ATM Role in Intermodal Transport (H2020-SESAR-ER4-10-2019)
Grant no. 891166
Duration: June 2020 – November 2022

Agenda

Time	Topic
10:00 – 10:30	**Welcome and Introduction** • Multimodality and Modus • SESAR and Europe‘s Rail
10:30 – 13:30	**Modus results presentations** • Introduction • Modal choice analysis • Passenger mobility modelling • Enablers and barriers | Recommendations
13:30 – 14:00	**Conclusions and next steps**

Moving Towards a Multimodal European Transport System

Manifold challenges ahead!

- Enabling a **seamless passenger journey**, including multiple providers, information and single ticketing
- Meeting **environmental goals** and facilitating a sustainable transport system
- Fair and efficient **pricing** across all transport (e.g., carbon pricing).
- Identifying and developing **new business models** that enable multimodal transport
- Multimodal framework, door-to-door oriented **passenger rights**.
- Rethinking the use of current **infrastructure** and future challenges

Multimodality: SESAR and Europe's Rail

SESAR Joint Undertaking

IMHOTEP	Airport's Passenger Flows
X-TEAM D2D	ConOps for seamless door-to-door mobility
synair.	Smart Contracts Framework
TRANSIT	Multimodal Performance Network
Modus	Future Multimodal (Joint Air-Rail) Scenarios

Europe's Rail

Travel Companion	My-TRAC, EXtenSive
Contractual Management Market Place	Co-Active
Asset Manager	IT2Rail
Multimodal trips / demonstrations	Shift2MaaS, Ride2Rail, IP4MaaS

Multimodal Transport

Luca Crecco

Gorazd Marinic

MODUS Final Event:
EU-Rail Research & Innovation activities

27/01/2023

Gorazd Marinic

Programme Manager

Europe’s Rail JU

Founding Members

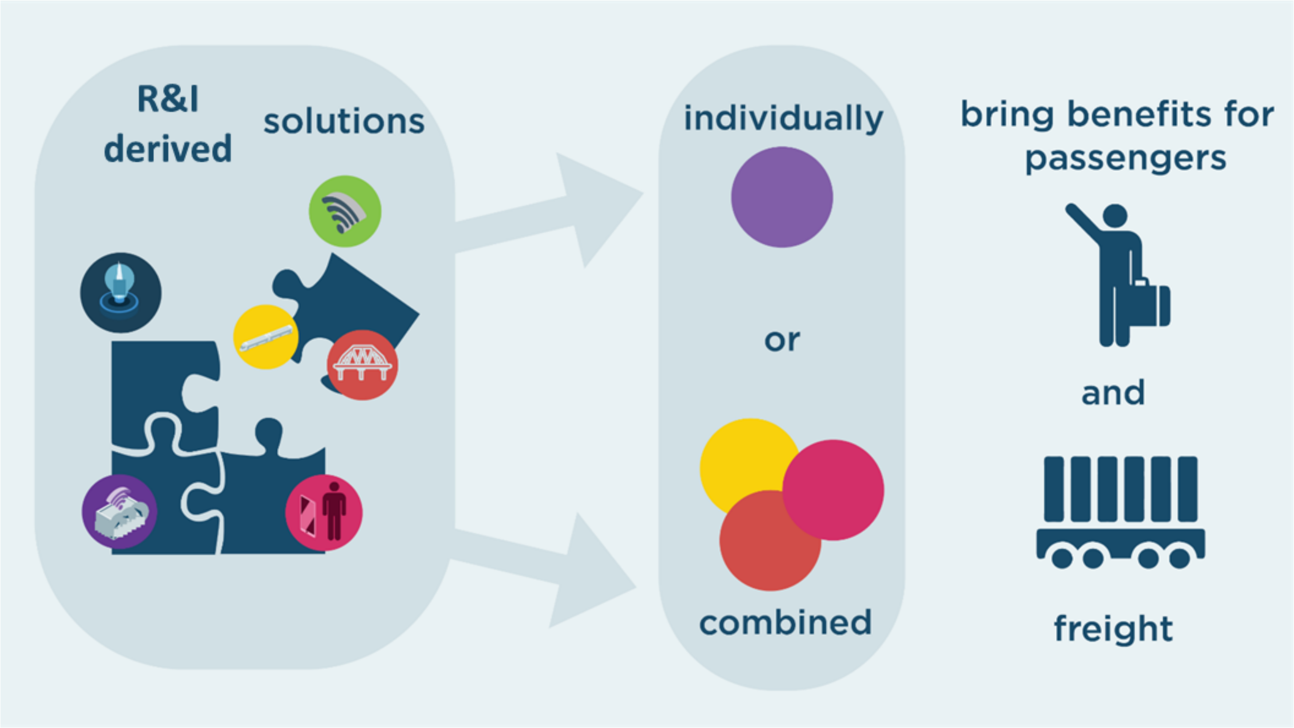
What is about EU-Rail?

VISION

To deliver, via an integrated system approach, a high capacity, flexible, multi-modal, sustainable and reliable integrated European railway network by eliminating barriers to interoperability and providing solutions for full integration, for European citizens and cargo

EU-Rail MISSION

- To make railway an everyday mobility through USER FIRST Research & Innovation



Rail: Our biggest opportunity

digital twin

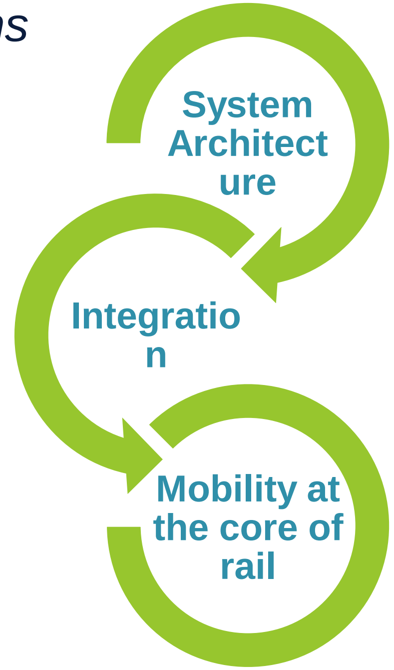
autonomous decisions

Rail is a network
Rail is a system
Rail is supervised
Rail is predictive
Rail is GREEN

→ *EU-Rail is delivering* ***coordinated EU system transformation*** *for the rail of the future through R&I and digital integration*

data driven processes

system management and interoperability



EU-Rail expected system impacts from the Programme

- Meeting evolving customer requirements
- Improved performance and capacity
- Reduced costs
- More sustainable and resilient transport
- Harmonised approach to evolution and greater adaptability
- Reinforced role for rail in European transport and mobility
- Improved EU rail supply industry competitiveness

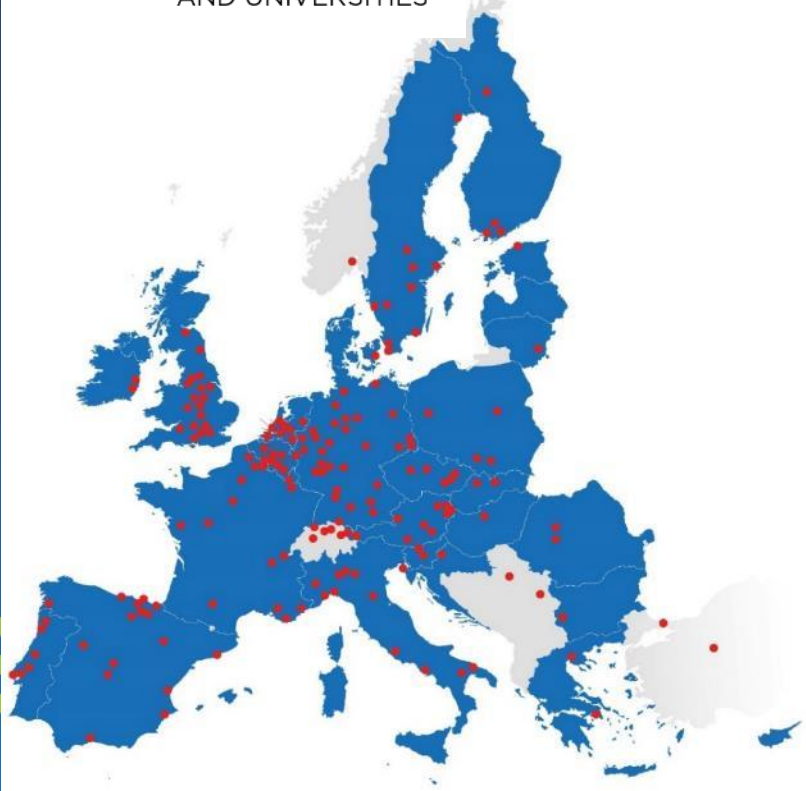
28
MEMBERS

412
PARTICIPANTS

29
COUNTRIES

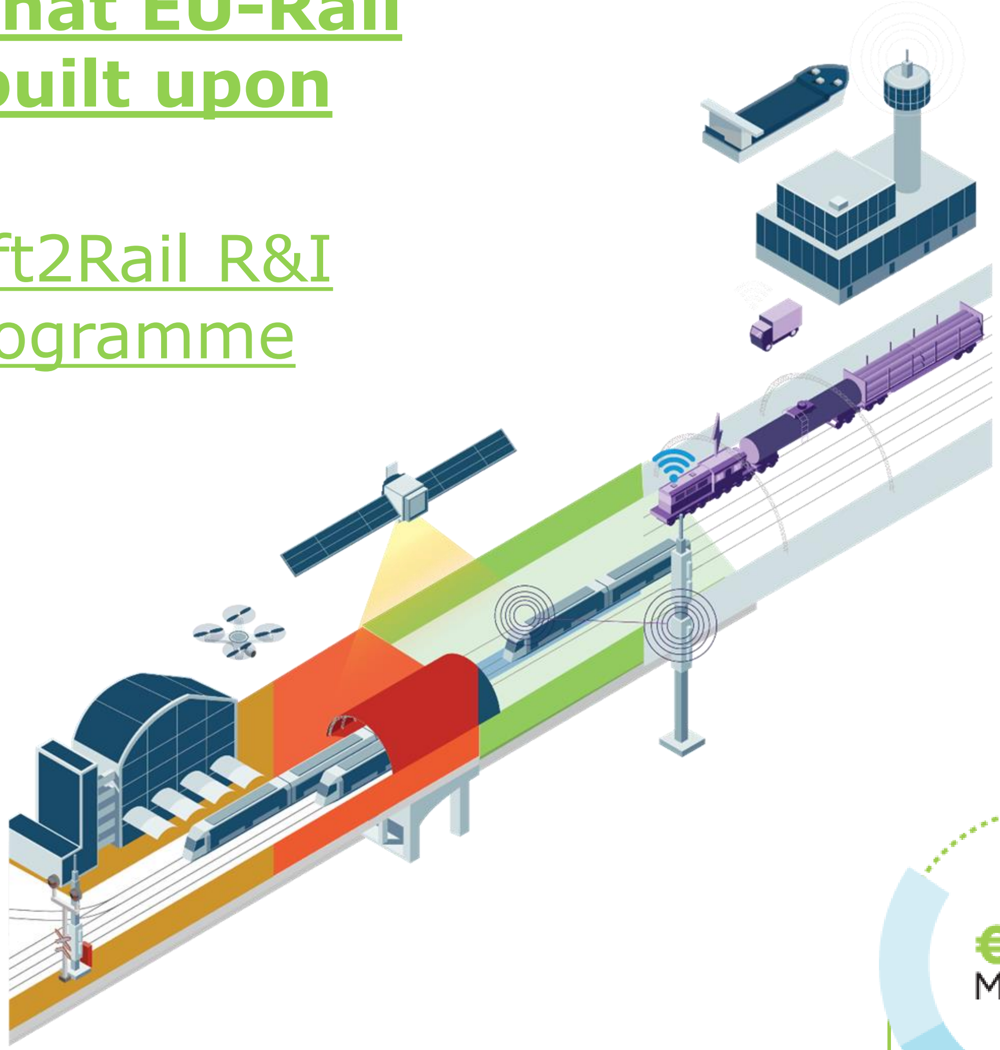
109
SMEs

113
RESEARCH CENTRES
AND UNIVERSITIES



On what EU-Rail is built upon

Shift2Rail R&I programme



IP1 Cost-efficient and Reliable Trains, including high-capacity trains and high speed trains

IP2 Advanced Traffic Management and Control System

IP3 Cost-efficient, Sustainable and Reliable High Capacity Infrastructure

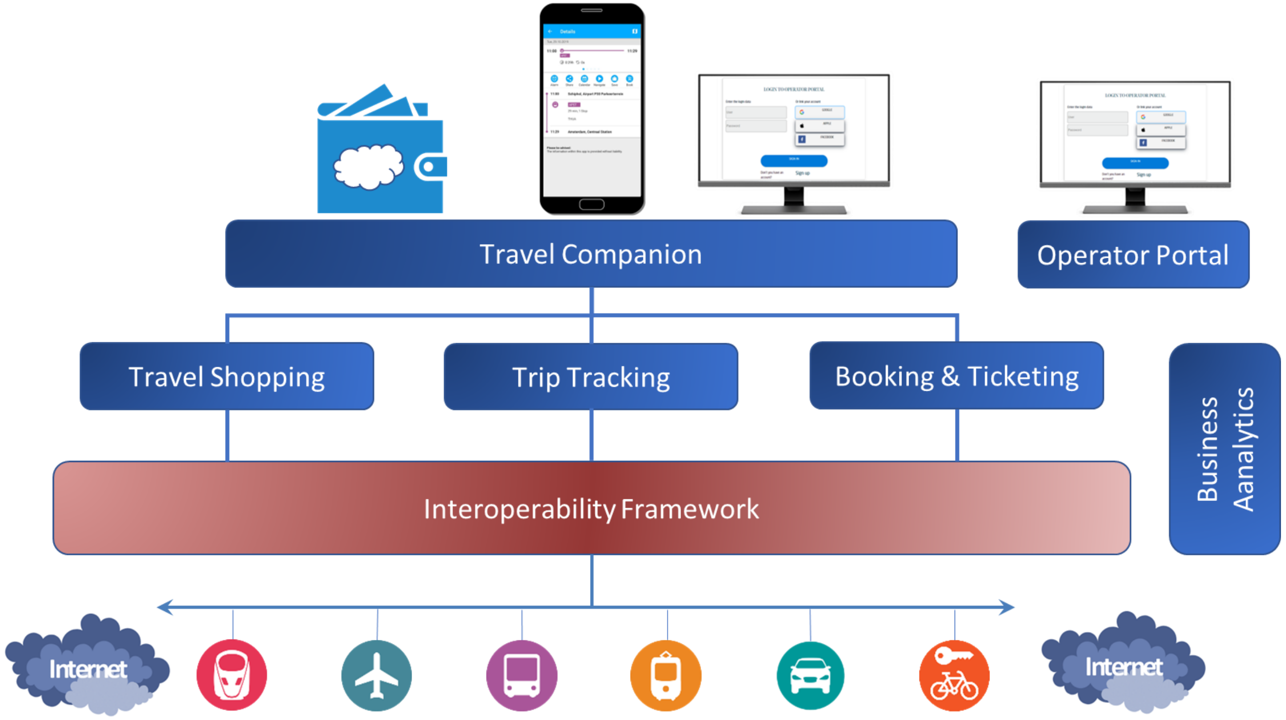
IP4 IT Solutions for Attractive Railways Services

IP5 Technology for Sustainable and Attractive European Rail Freight

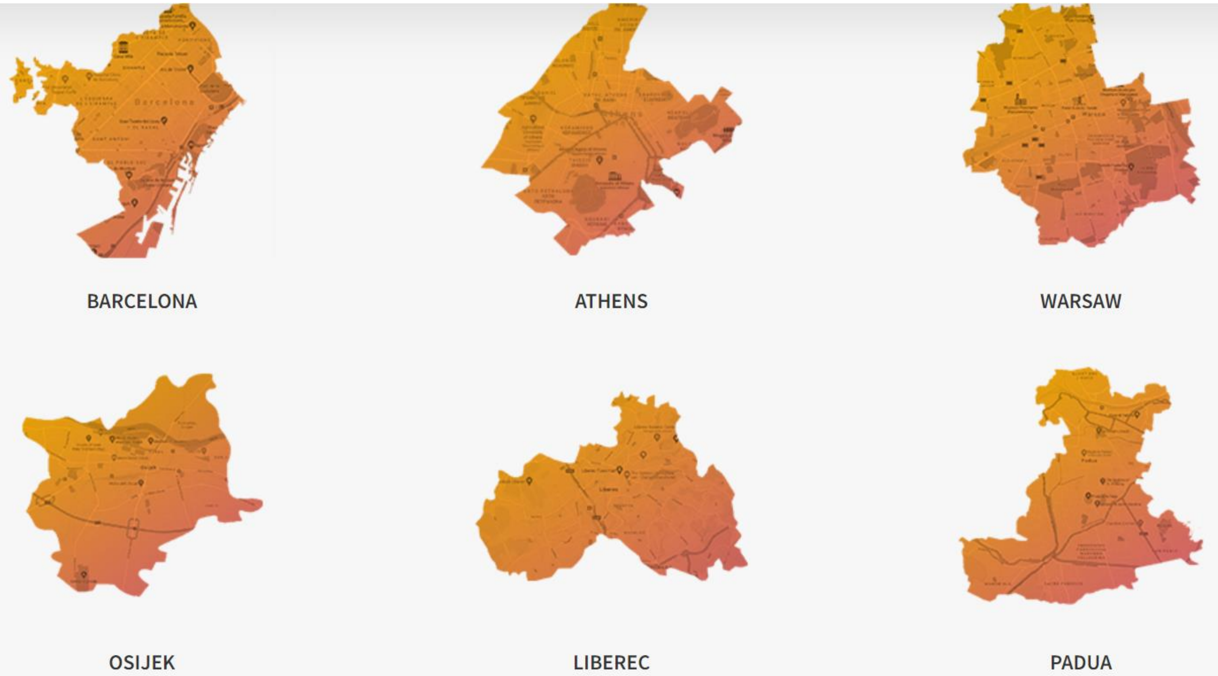
CCA Cross Cutting Activities

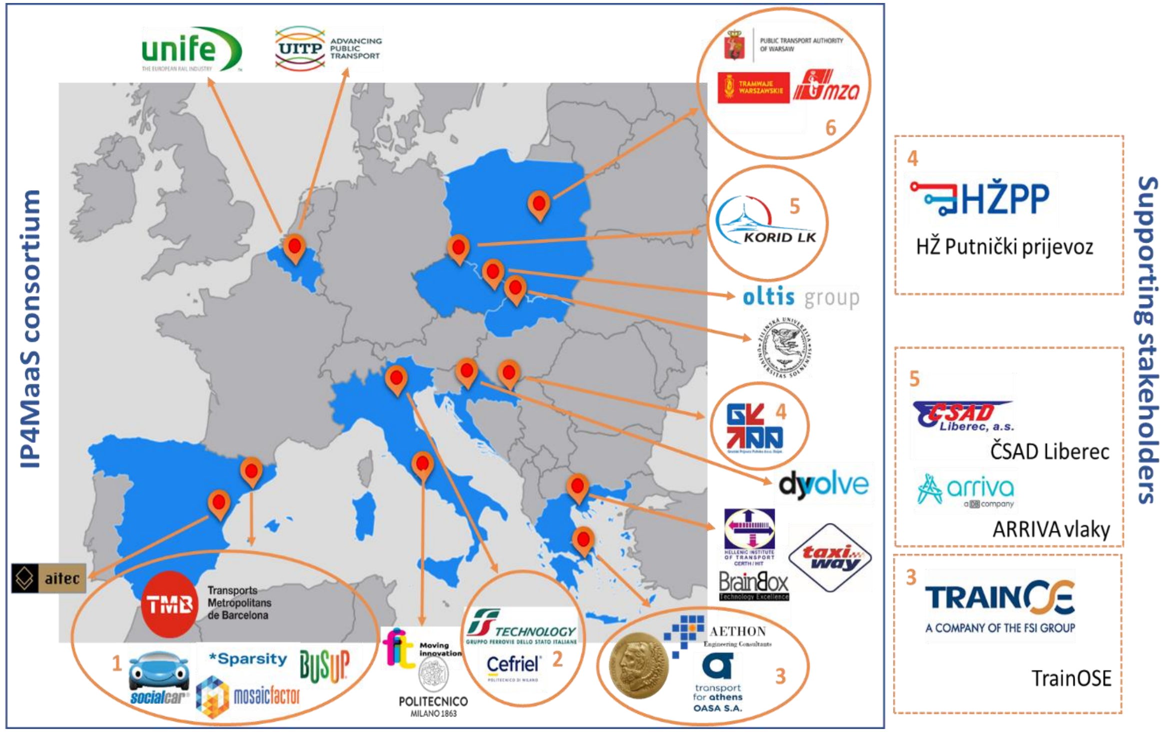
IP4: Multimodal ecosystem

Contains all necessary functions to provide an attractive solution for travellers – mode independent, cross border and European wide.



Piloting activities: IP4MaaS, Ride2Rail





DELIVER AN **INTEGRATED EUROPEAN RAILWAY NETWORK** BY DESIGN

DEVELOP A **UNIFIED OPERATIONAL CONCEPT AND A FUNCTIONAL SYSTEM ARCHITECTURE** FOR INTEGRATED EUROPEAN RAIL TRAFFIC AND CCS/AUTOMATION

DELIVER A **SUSTAINABLE AND RESILIENT RAIL SYSTEM**

DELIVER A **COMPETITIVE, GREEN RAIL FREIGHT** FULLY INTEGRATED INTO THE LOGISTICS VALUE CHAIN

DEVELOP A **STRONG AND GLOBALLY COMPETITIVE EUROPEAN RAIL INDUSTRY**

EUROPE'S RAIL:

ONE INTEGRATED R&I PROGRAMME

SYSTEM PILLAR

OPERATIONAL CONCEPTS | FUNCTIONAL SYSTEM ARCHITECTURE

A SINGLE COORDINATING BODY FOR THE WHOLE SECTOR EVOLUTION

OPEN INTERFACES TO OTHER TRANSPORT MODES AND BUSINESSES | SYSTEM REQUIREMENT SPECIFICATIONS

INNOVATION PILLAR

TECHNOLOGICAL AND OPERATIONAL SOLUTIONS FOR SERVICES OF FUTURE

FLAGSHIP PROJECTS

LARGE-SCALE DEMONSTRATIONS

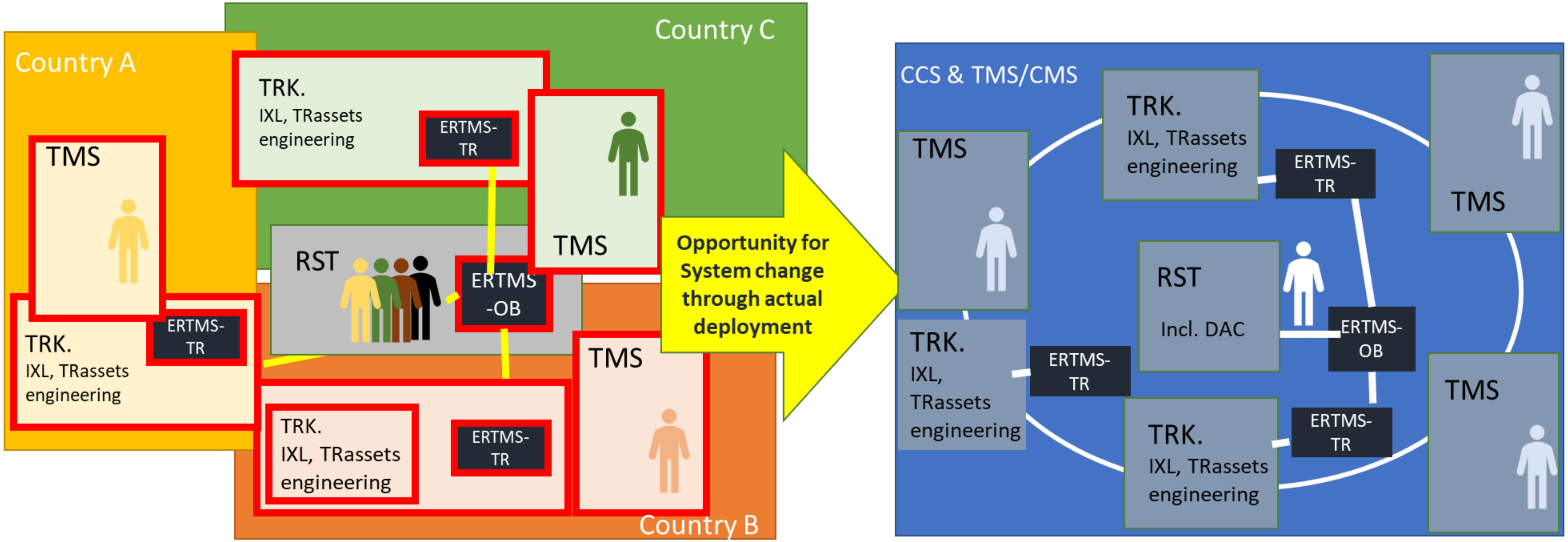
EXPLORATORY AND FUNDAMENTAL R&I

1	**EUROPEAN RAIL TRAFFIC AND MOBILITY MANAGEMENT**	Manage and improve rail traffic at EU level Adjust rail traffic management in function of the mobility demand
2	**DIGITALISATION & AUTOMATION IN TRAIN OPERATIONS**	ATO implementation Digital train operations
3	**SUSTAINABLE AND DIGITAL ASSETS**	Integrated assets testing & life-cycle framework Zero-emmission, silent rail system
4	**COMPETITIVE, DIGITAL, GREEN RAIL FREIGHT**	New digital customer interaction & innovative rail freight services Multimodal and rail freight innovation integration
5	**REGIONAL RAIL SERVICES IN LOW DENSITY AREAS**	New system approach to regional rail services in low density areas

DEPLOYMENT GROUP

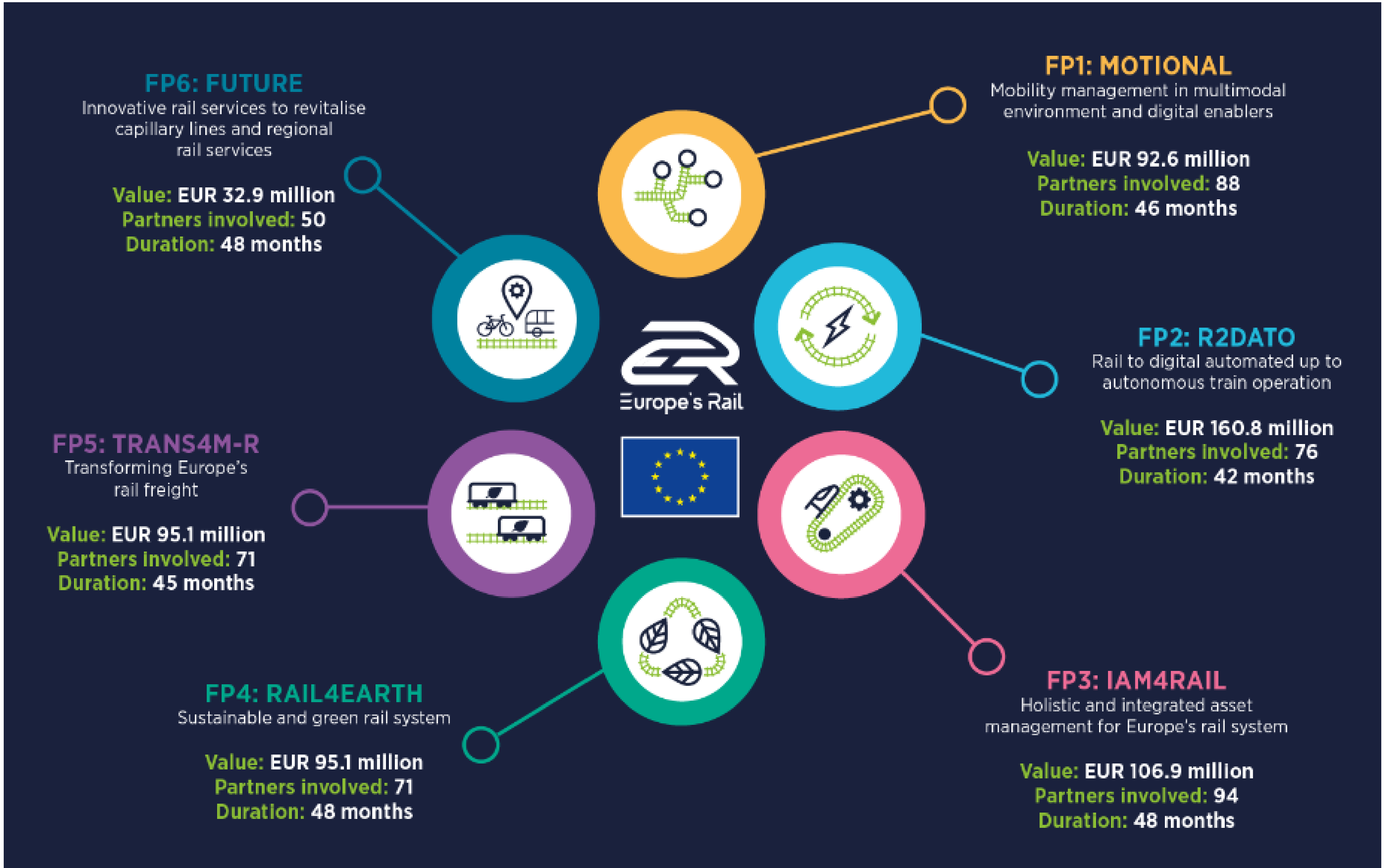
FUTURE SOLUTIONS DEPLOYED IN A COORDINATED AND CONSISTENT WAY AT EUROPEAN LEVEL, TAKING INTO ACCOUNT ALTERNATIVE ROLLOUT SCENARIOS, BEHAVIOURAL AND ORGANISATIONAL CHANGES, SYNERGIES WITH OTHER MODES OF TRANSPORT

System Pillar

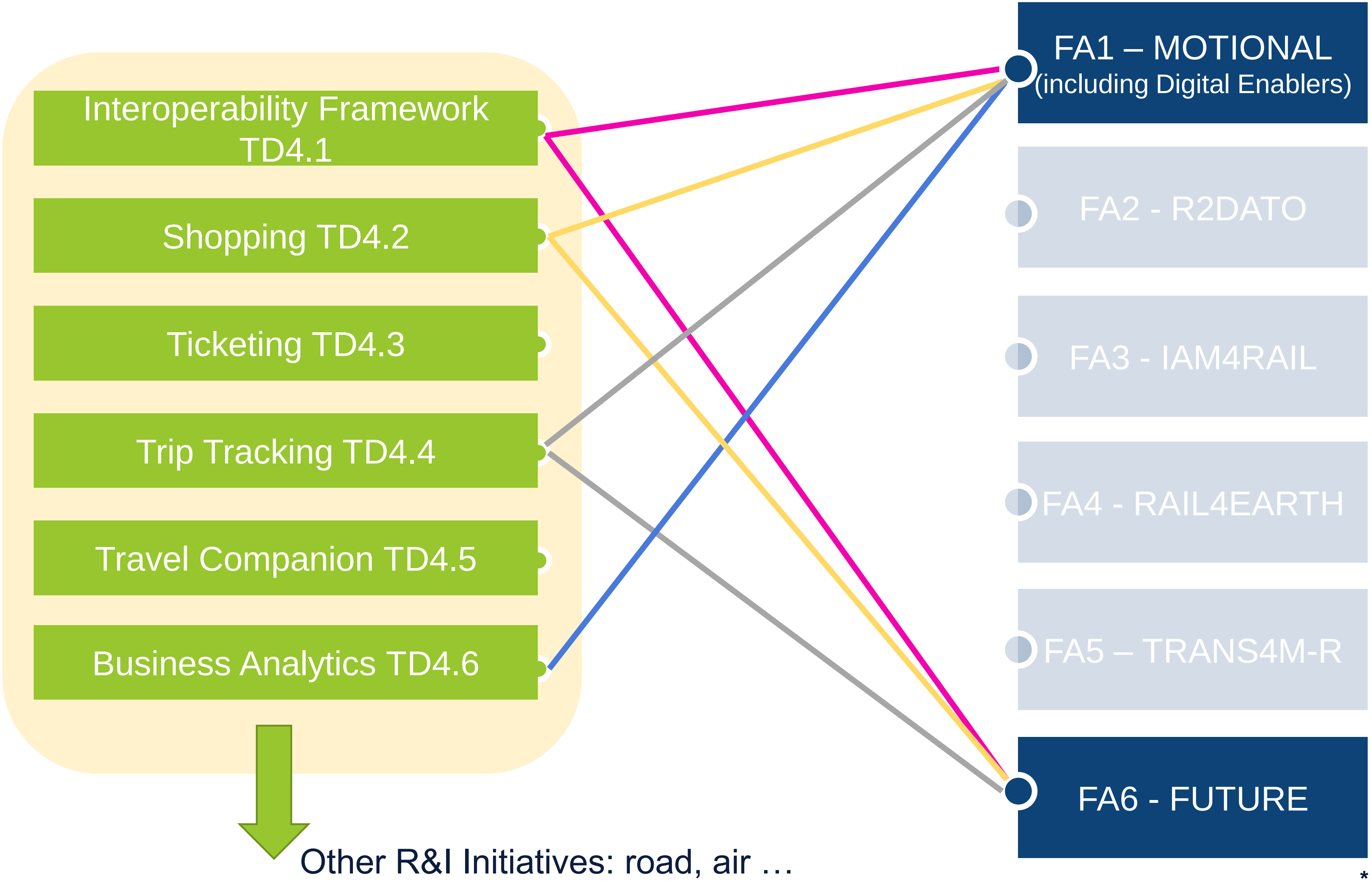


System Pillar is the opportunity for the sector to converge on the evolution of the Railway system - operational concept and system architecture

The first EU-Rail flagship projects



Transfer of results of IP4 projects*



* Preliminary analysis

FP1-MOTIONAL: Network management, planning, and control & mobility management in a multimodal environment and Digital Enablers

- Dynamic real-time traffic management
- **Managing traffic on demand, supporting door-to-door services**
- **Connecting TMS to relevant subsystems that influence traffic**
- Capacity optimization and automatic management of cross-border traffic
- **Integrate rail with other transport modes**
- Digital Twin environment, Conceptual Data Model (CDM) and Federated Dataspaces

FP6-FUTURE: Regional rail services / Innovative rail services to revitalise capillary lines

- Regional Railway System (CCS & Operations) Demonstration
  - integrated Operations Control Center covering interlocking, radio blocking and TM
  - simple on-track radio network (FRMCS)
  - Specific TMS for regional lines
  - safe environment perception solutions
- Assets Demonstration
  - cost-efficient wireless, energy self-sufficient wayside components (e.g. switches, level crossings)
- Suitable customer services
  - cost-efficient on-board information on **regional multimodal services** (e.g. carsharing)
  - passenger congestion rate monitoring, flow optimization application, low-cost passenger information system

Areas of potential collaboration Air - Rail

- Connected Air and Rail Traffic Management Systems (ATM – TMS)
- Coordinated planning
- Coordinated operations
- Disruption management
- Open opportunities for new business models
- Real-life piloting of solutions: regional or High-Speed lines, important airports

Potential joint call SESAR - EU-Rail

- Established collaboration
- Joint participation to different forums (e.g. IRP)
- EU-Rail next Call: Q4 2023
- Engage with ERRAC to contribute to Programme/call development

Europe’s Rail Innovation Days

7-9 December 2022, Online

- Expert led technical sessions across several days
- Latest results and progress of the Shift2Rail projects

Recordings and presentations:

https://rail-research.europa.eu/calendar/europes-rail-2022-innovation-days//

Thank you for your attention!

White Atrium Building, 2nd Floor
Avenue de la Toison d’Or 56-60
B1060, Brussels - Belgium

www.rail-research.europa.eu

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Agenda: Modus Results Presentations

Topic	Presenter
Introduction	Annika Paul (BHL)
Modal choice analysis	Isabelle Laplace (ENAC)
Passenger mobility modelling	Elham Zareian (UoW) Hamid Kadour (ECTL)
Enablers and barriers | Recommendations	Vanessa Perez (UIC)

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Introduction

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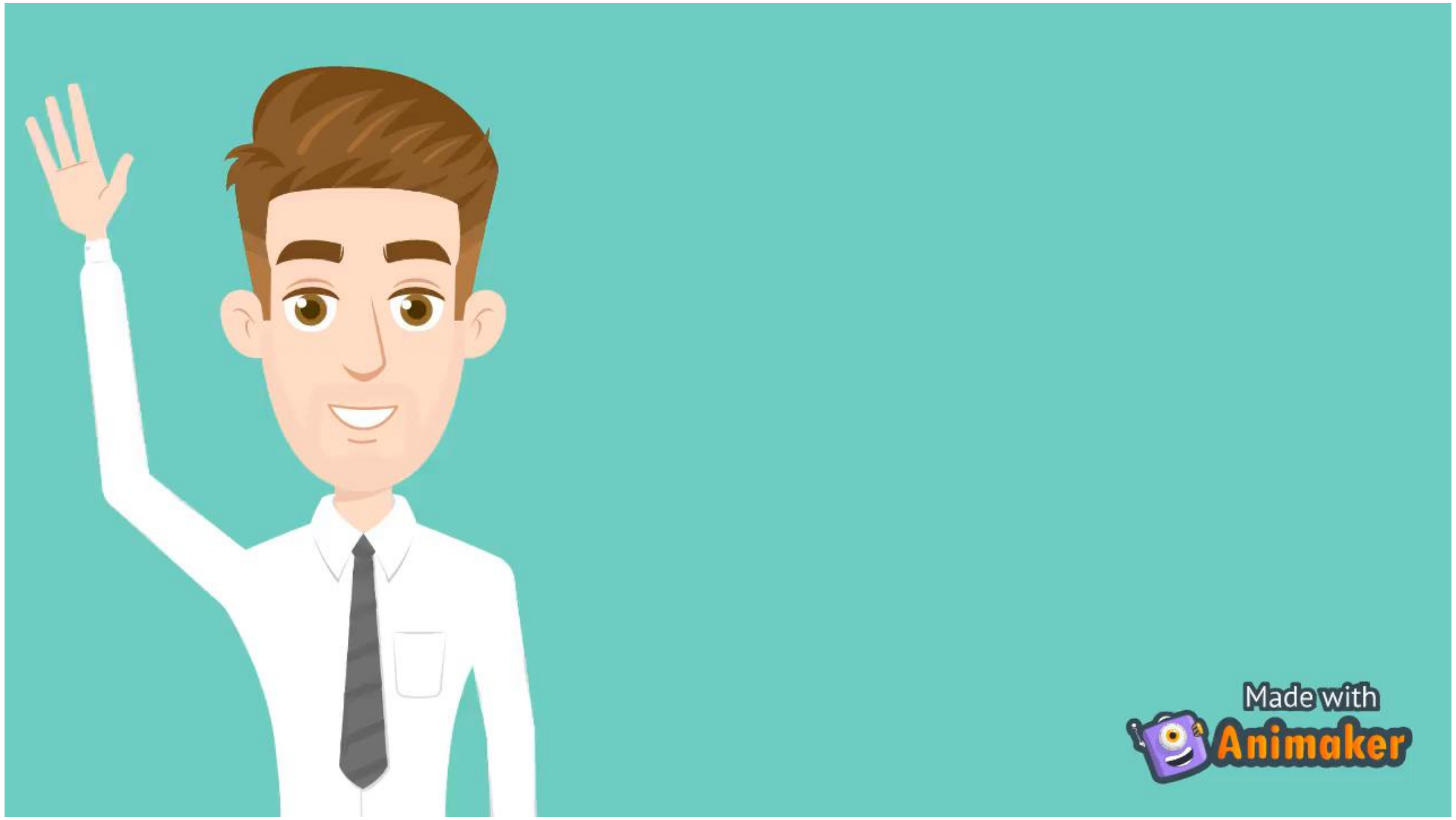
A Multimodal Journey



Joint Air-Rail Mobility in Europe

Substitution and/ or complementarity between air and rail

- Restrictions and replacement of short-haul flights (via bans/ incentives)
- High-speed rail as connecting mode for airports, enlargement of catchment areas
- Multimodal cooperation to facilitate synergies (*e.g.*, Deutsche Bahn as Star Alliance Member)
- Rescheduling in case of disruptions or delays

Consideration of **door-to-door travel chain** and **passenger expectations**

European short-haul flight and rail network

Objectives and Approach

- The **overall performance of the (future) European transport system** will strongly depend on the alignment and optimisation of multimodal transport.
- To better understand and assess the impact of **air and rail as substitutes and complements**.
- Understand and assess different **traveller behaviour** on door-to-door journeys.
- With the help of **Modus scenarios**, to obtain insights into possible future development paths of European mobility.
- Development of innovative approach towards **data-driven, integrated air-rail modelling**, considering **passenger door-to-door (D2D) itineraries.**
- Evaluate the **impact** of an improved, joint air-rail transport system on **different key performance areas** (*e.g.*, D2D travel times, CO_2 per passenger).

Modus Approach

Understand
Multimodal door-to-door mobility

Explore and model
Multimodal performance assessment

Identify
Way forward

Drivers for supply and demand

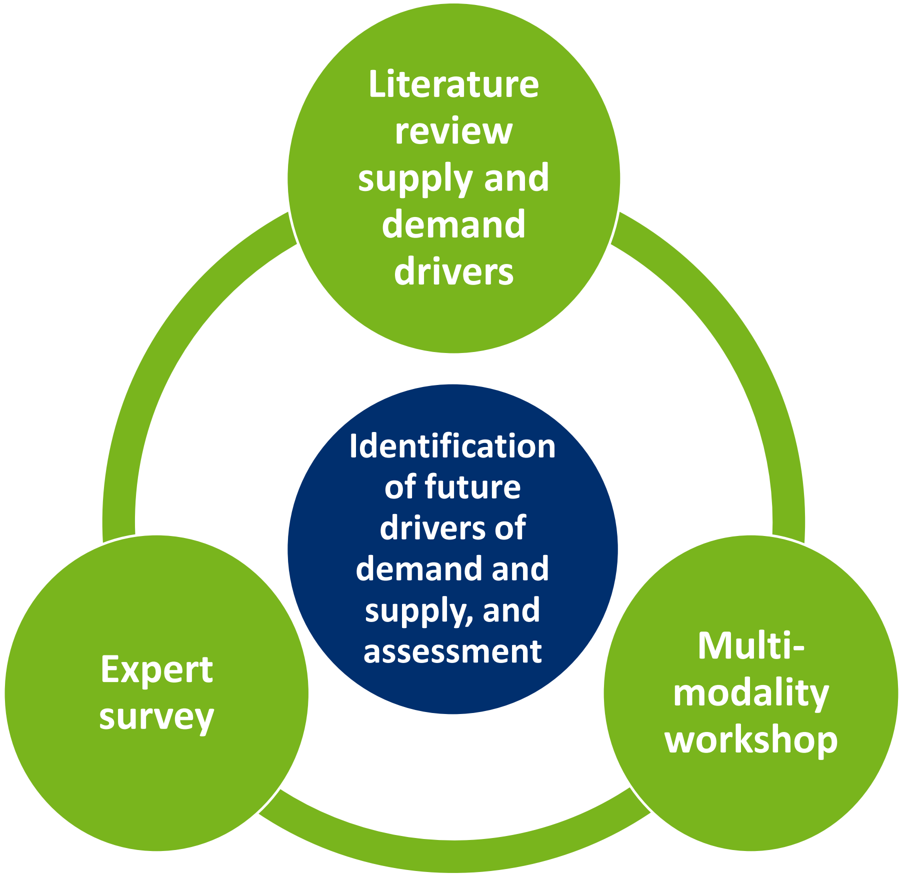
European transport objectives and goals

(1) Modus scenarios
(2) Traveller archetypes
(3) Modal choice analysis

(1) Connectivity and performance indicators
(2) Passenger mobility and flight-centric modelling

(1) Identification of gaps and barriers
(2) Recommendations

Drivers



Modus approach to identify supply and demand drivers

Social
- Population change (size and age)
- Health concerns
- Motive of travel

Technological
- Communication technologies
- Connectivity
- Artificial intelligence (AI)

Economic
- Change in disposable income
- Intermodal cooperation and ticketing; MaaS

Environmental
- Environmental attitudes and willingness to change behaviour

Political
- Regulatory change - passenger rights, various modes

Mobility
- Travel time
- Change in tourism patterns
- Interoperability

Selection of drivers has been applied for scenario development, modal choice and passenger mobility modelling

Analysing Future Multimodal Pathways

- Development of **future multimodal scenarios for European joint air-rail transport**
- Derived from **European high-level mobility objectives**, existing scenario studies as well as the work conducted within the Modus project
- Focus on particular aspects envisaged for the future, and that have the potential to significantly change the transport system

European high-level mobility objectives (extract)

Mobility goals	Definition
Connectivity	Reduction of travel time; Connection of remote regions
Environmental impact	Reduced reliance on fossil fuel; Reduction of CO_2 emissions; Internalisation external costs
Integration and additional demand	Meeting increasing transport demand by adjusting and extending capacities; More efficient resource allocation within transport network
Technological innovation and (widespread) implementation	Develop more fuel-efficient, hydrogen-powered and (hybrid-)electric aircraft and bring these into operation through continued fleet renewal; Ensure that low and zero emission technology options are deployed, including through retrofitting and appropriate renewal schemes in all transport modes

Source: Modus Deliverable D3.2 (2021)

Multimodal Scenarios

Scenario 1: Pre-pandemic recovery

- 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: Decentralised, remote and digital mobility

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

Application and challenges

- Not mutually exclusive: different regions may develop features of several scenarios
- Four multimodal scenarios with a time horizon 2040+
- Parametrisation of variables and data availability challenging
- Focus on specific 'experiments' (re. Scenario 1-3) in passenger D2D mobility modelling

Passenger Archetypes

Including a differentiated traveller perspective, *e.g.*,

- Trip purpose
- Price elasticities
- Value of time
- Environmental awareness
- Travel group size
- Frequency of travel
- …

Business

Leisure

Visiting Friends and Relatives

More detailed approach to passenger segmentation

Business Flyer

Digital Gen Z Flyer

Environment-minded Flyer

Premium Flyer

Cultural Jetsetter

Holidayer

Golden Senior Flyer

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Modal choice modelling

Pierre Arich[1], Tanja Bolic[2], **Isabelle Laplace[1]**, Nathalie Lenoir[1], Sébastien Parenty[1], Annika Paul[3], Chantal Roucolle[1]

[1]Ecole Nationale de l'Aviation Civile, [2]University of Westminster, [3]Bauhaus Lufthart

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Motivation

- Identifying the determinants of passengers’ choice of transportation
- Assessing the substitution paths of demand between air and rail
- Assessing potential trends in the distribution of market shares in Modus scenarios

Literature review

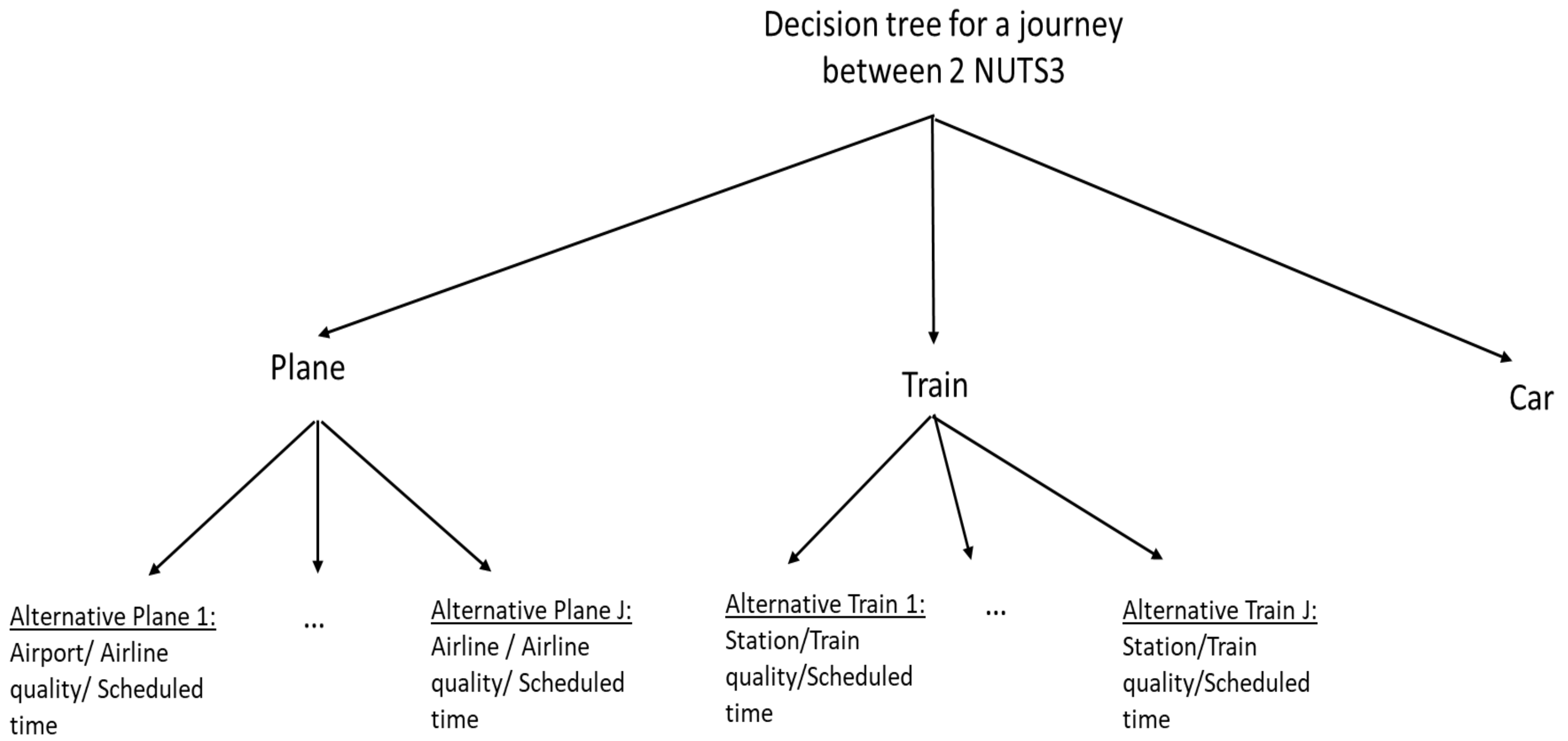
- Inter-modal competition has been extensively studied in the literature
  - Most focus on air-rail competition only ((Albalate et al., 2015), (Behrens & Pels, 2012), (Ortúzar & Simonetti, 2008), (Park & Ha, 2006), (Ivaldi & Vibes, 2008))
  - Others consider sets of other modal alternatives as bus, car-pooling and private cars (Bergantino & Madio, 2020)
- Some authors consider inter and intra-modal competition (Bergantino et al. 2015),(Ivaldi & Vibes, 2008))
- In this paper, we ambition to go ahead with the work of Ivaldi and Vibes (2008) by considering a much larger network

City-pairs and transport supply

- City-pair definition and selection
  - Selection of geographic areas larger than the cities: NUTS3 level
    - ➢ *Several airports and railway stations in departure and arrival OD*
  - Selection of OD where both air and rail are available – direct routes
  - Characterization of demand on city-pairs : socio-economic indicators

- Transport supply
  - Train: HSR, Intercity, Night
  - Plane: Majors, Low-Cost Carriers
    - ➢ *Major supply: HSR, Legacy carriers*
    - ➢ *Low-cost supply: Intercity, Night, Low-cost carriers*
  - Car as another possible mode of transportation

A two-stages decision model

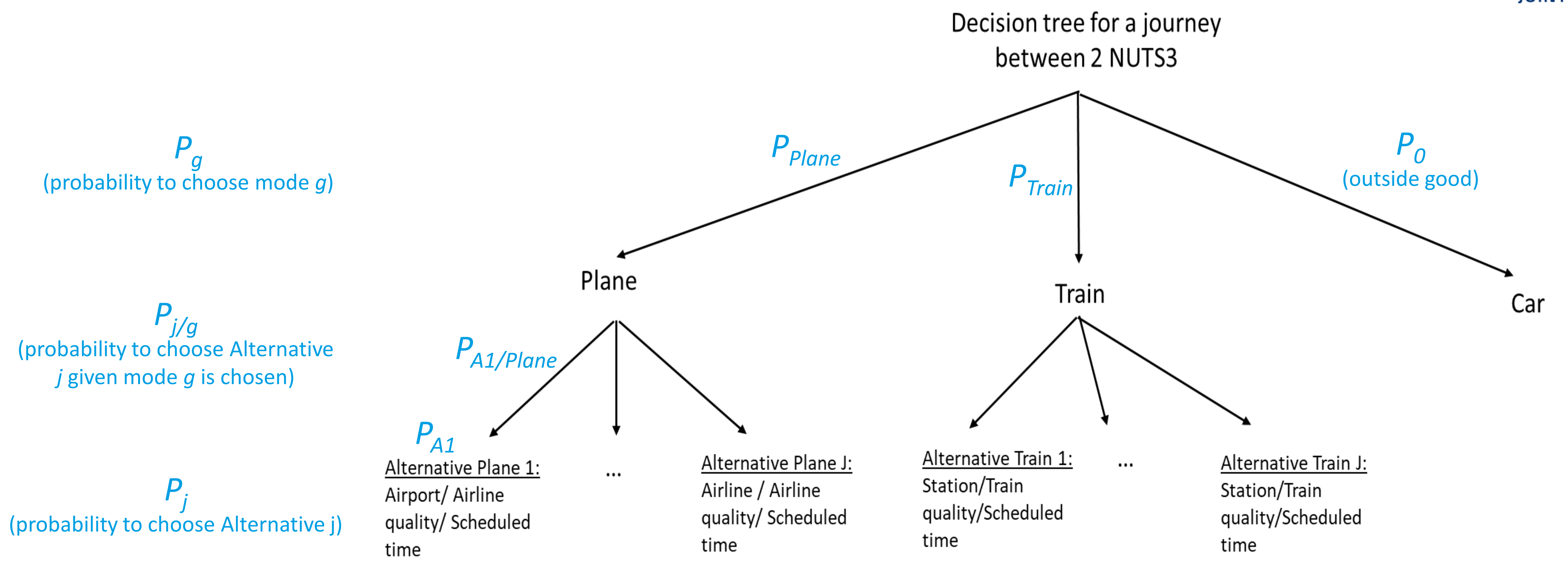


Alternative: combinaison of a mode, service provider, type of service & corresponding price

Objectives of the model:

- ➢ *Determining what is the intensity of competition between modes: intermodal competition*
- ➢ *Determining what is the intensity of competition within modes: intramodal competition*

Theoritical model



P_j, $P_{j/g}$, P_g : theoretical probabilities

- we observe the empirical probabilities: market share s_j, $s_{j/g}$, s_g

$\sum_j P_j = 1$ and $\sum_j s_j = 1$

Demand is expressed in terms of market share

Demand function

$$ln(s_j) - ln(s_0) = \psi_j + hp_j + \sigma ln(s_{j/g})$$

- s_j : market share of alternative *j*
- $s_{j/g}$: market share of alternative *j* given the choice of mode *g*
- s_0 : market share of the outside good - assumed to equal 0.85
- ψ_j : vector of characteristics for the alternative j
  - type of the service; city or airport departure/arrival; scheduled day and time; distance
  - proxy for the size of the market, GDP or population or household average income in departure and arrival areas
- p_j : price of alternative *j*
- h : part of the measure of demand sensitivity to price
- σ : measure of the degree of intra-group correlation; σ belongs to [0,1]

Data collection

Network

French, German and Spanish domestic origin-destination (NUTS3 level) where air and rail transport modes are in competition

Data sources:

For air: OAG Schedule Analyzer, FRACS (France Aviation Civile Services) database, airline annual reports, IATA paxIS

For rail: MERITS (UIC database), SNCF, RENFE

A unique air and rail aggregated database in 2016

Per OD, per alternative, per month

We observe the frequency, the total number of passengers and the average price

➢ *frequency is used as a weight in our analysis*.

We also observe several characteristics:

- For the alternatives: % of departure during the week-end, % of departure across several time slots, distance
- For the OD, socio-economic characteristics: GDP, population, GDP/capita

Estimation - results

- One model per country
- Statistical significance of the estimated parameters
- Validity of the instruments
- ***Price:*** correct negative sign
- ***Intra-mode competition:*** high for Germany and Spain, low for France

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

Measures of demand sensitivity

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Price elasticity of demand

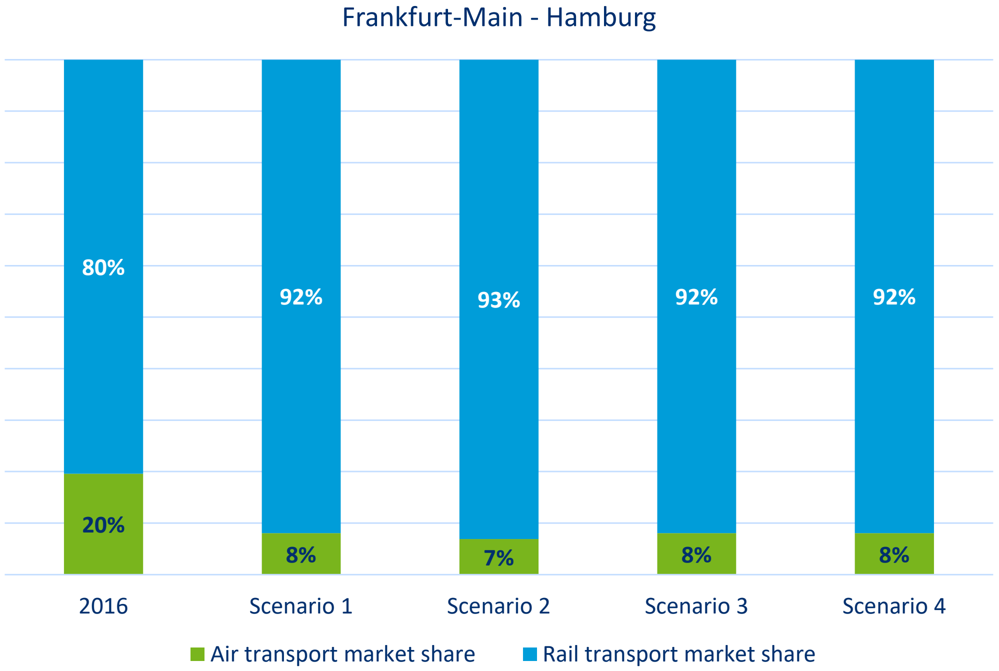
$$\eta_j = \frac{dq_j}{dp_j} \times \frac{p_j}{q_j} = hp_j \left(s_j - \frac{1}{1-\sigma} + \frac{\sigma}{1-\sigma} s_{j/g} \right)$$

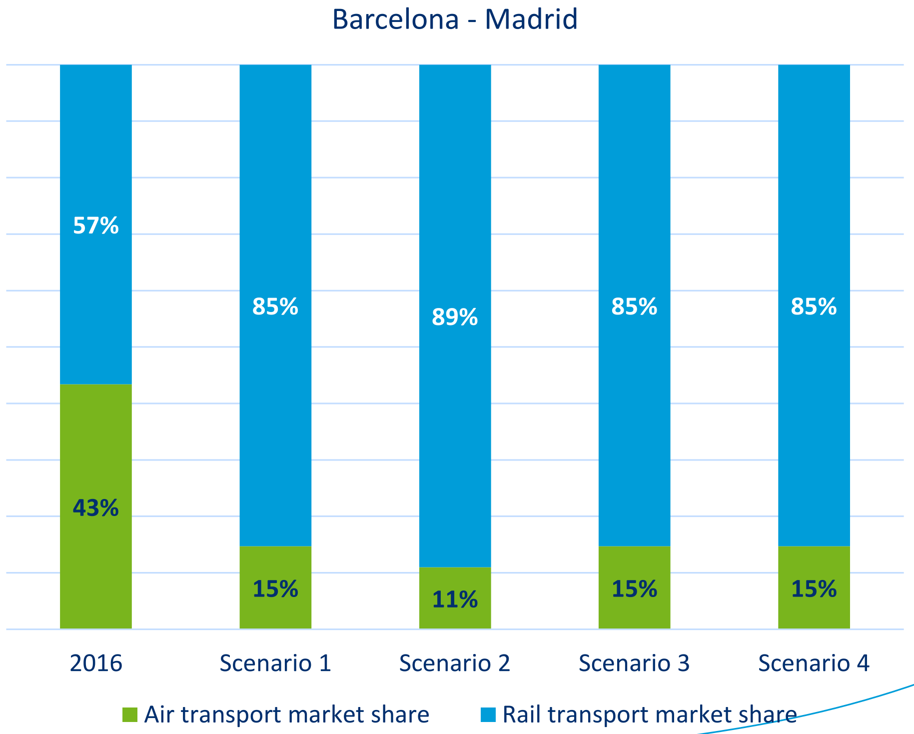
Country	Obs	Mean	Std. Dev.
France	1,961	-5.338775	1.5893
Germany	2,582	-9.111078	7.718956
Spain	272	-10.78422	9.738804

Price elasticities of demand	France		Germany		Spain	
	Major	Low-cost	Major	Low-cost	Major	Low-cost
Plane	-6.03 (1.18)	-4.74 (1.90)	-6.11 (7.04)	-13.54 (6.99)	-17.58 (7.06)	-28.53 (0.55)
Train	-5.21 (1.39)	-3.01 (1.54)	-4.62 (4.13)	-13.44 (7.824)	-1.53 (0.37)	-14.32 (6.23)

Development of demand and supply scenarios: illustrations of potential impacts on market shares

- Model has been assessed for the four scenarios on each considered city-pair: **results do not have to be considered as forecasts but show potential trends in the distribution of market shares**
- Some illustrations due to the strong price sensitivity of air transport demand





Conclusion

- <u>Main results</u>
  - Strong sensitivity of demand to changes in fares leading to substitution between transport mode
  - Intra-mode competition: high for Germany and Spain, lower for France
  - Higher price sensitivity of travelers using low-cost supply in Germany and Spain
  - Higher price sensitivity of air travelers compared to rail travelers

- <u>Further potential work:</u>

  Investigate on the characteristics of the supply (frequency, days and hours of departure) that regulators should consider to influence the PAX choice towards choices that could be more valued from a societal point of view.

SESAR JOINT UNDERTAKING

Modus

Passenger Mobility Modelling in Modus

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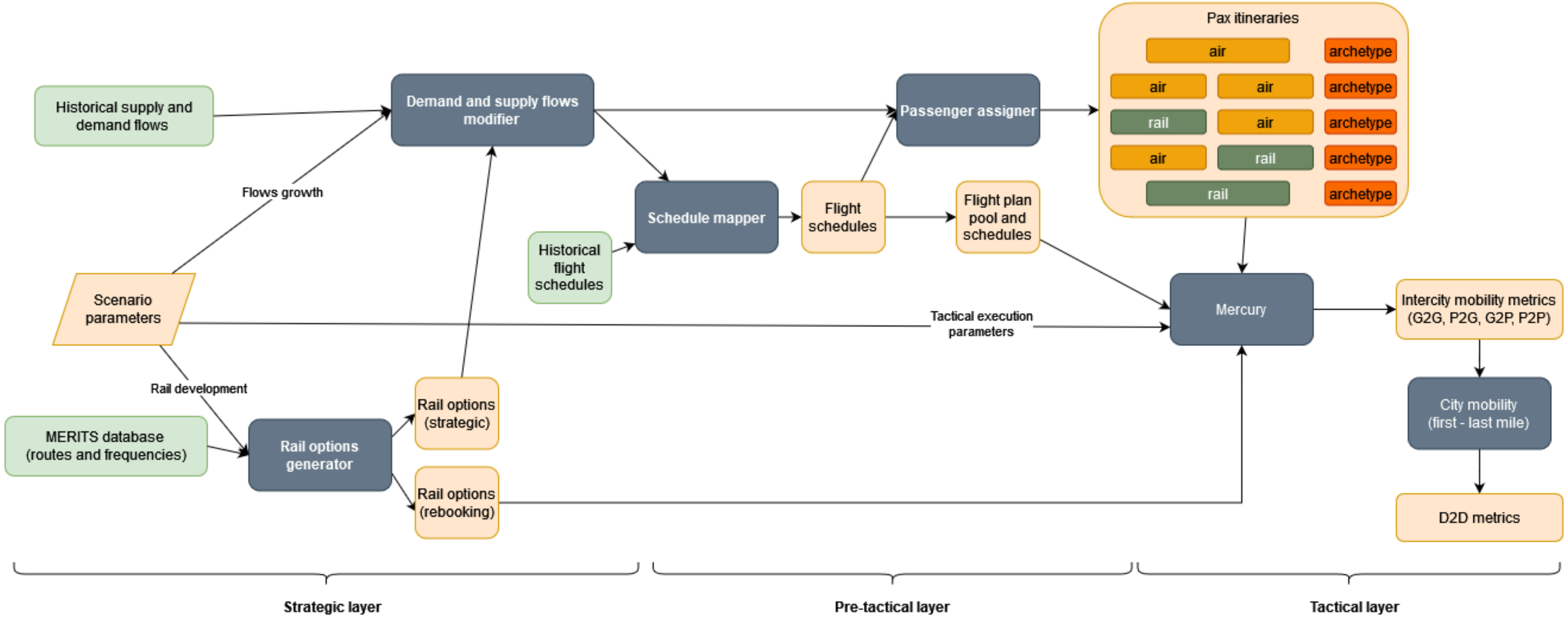
Overview

- ❑ *The brief introduction of two passenger mobility models (Mercury & R-NEST)*
- ❑ *What are the modelling assumptions of these two models?*
- ❑ *How do these models perform?*
- ❑ *Lessons learned.*

Multimodal Passenger Mobility Modelling

- Mercury focused on the modelling of the G2G phase of the passenger itineraries.
- The model has been expanded to consider multimodal journeys.
- The model covers three phases of transport



Generating demand and supply flows and rail alternatives.

Translate flows into individual schedules and passenger itineraries.

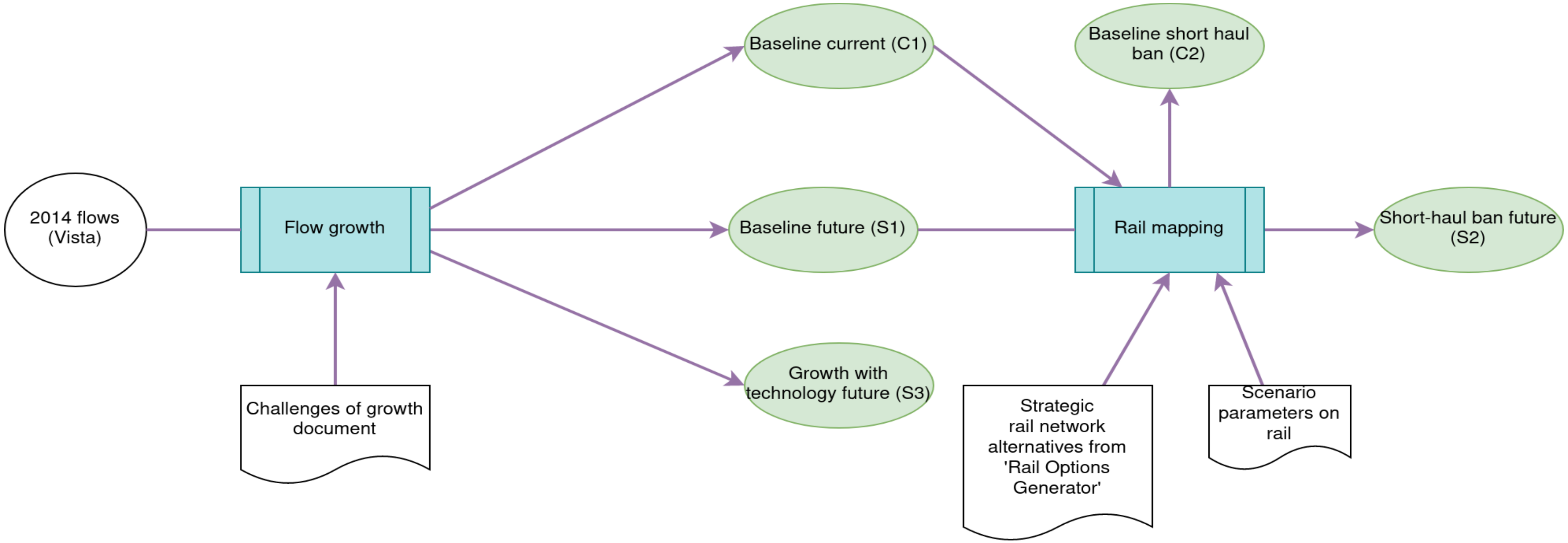
Execution of the itineraries in the tactical layer (+ disruptions).

City Archetypes

<table>
<tr><th>City archetype</th><th>Airport archetype</th><th>Railway connection to airport</th><th>Further railway info</th></tr>
<tr><td>Arch-1</td><td>Main hub</td><td>Good inter-regional, direct HSR to airport</td><td>-</td></tr>
<tr><td>Arch-2</td><td>Main hub</td><td>Good inter-regional, no direct HSR to airport</td><td>HSR connected to the City Only</td></tr>
<tr><td>Arch-3</td><td>Secondary hub</td><td>Good inter-regional, no direct HSR to airport</td><td rowspan="3">HRS connected to the region only and/or good mainline rail</td></tr>
<tr><td>Arch-4</td><td>Large/Medium</td><td>Good interregional, no direct HSR to airport</td></tr>
<tr><td>Arch-5</td><td>National/regional</td><td>Near good inter-regional/ NO HSR</td></tr>
</table>

Demand and Supply Flows Modifier

- The demand and supply flows modifier component lies in the strategic layer, which produces the future flows and passenger itineraries.
- Flows represent the future supply of seats, while passenger itineraries represent the future demand in aggregated volume of passengers.
- The generated supply and demand volumes are varied across scenarios.



Schedule Mapper and Passenger Assigner

Schedule mapper

For each experiment individual airline schedules and planned flight rotations are generated.

Required inputs:

- airport data,
- (historical) flight schedules,
- turnaround times,
- aircraft data (e.g. aircraft leasing prices, aircraft ranges), as new aircraft need to be added to the schedules,
- supply data (e.g. number of seats per origin-destination)
- airline data (e.g. type of airline).

Passenger assigner

Creates future passenger itineraries and requires the following inputs:

- future schedule generated by the schedule mapper,
- future itineraries, created in the flow modifier component,
- airport data (e.g. coordinates, minimum connecting time).

The passenger assigner considers actual seat capacity as provided by the schedules and connecting times.

Rail Layer Modelling

Rail options generator

Exploring interconnectivity between air and rail

New layer of Mercury to find rail alternatives to scheduled air routes (total substitution of air; collaboration of both means of transport

Rail-based parameters for each possible direct rail route (fed into flow modifier and Mercury):

- Average travel time
- Average waiting time
- Time of first/ last train of the day

1. **Rail station-airport mapping**

Railway stations within 40km of an airport are selected.

2. **Rail data processing**

Find existing rail routes to substitute air routes

3. **Waiting time estimation**

Calculated for given route, computing each waiting time and mean; expected waiting time as a result

Introduction of Use Cases

Strategic route planning

Rail as a substitute and complement of air itineraries (full replacement of the whole trip or connection to/from the hub).

- Demand and supply modifier application
- Focus on Spain, Italy, France and Germany (development of high-speed rail network).
- Options: 1. the rail station located at the hub, 2. the rail station located in the city centre.
- Estimation of multimodal segments for different airports.

Tactical disruption management

Two regions impacted by a large air disruption, rail to reroute some of affected passengers.

- Madrid and Paris regions.
- All rail schedules are considered, regardless of the countries involved, duration, speed (high speed rail/regular) and distance.
- Cancellation of 90% of short-haul flights
- Comparison to rail network and cities directly reachable by train
- For current baseline, future baseline and future baseline with short-haul ban: trip cancellation if no rail connection/ rail journey twice as long
- For future high growth with technology: Rail option with higher utility (thrice journey time allowed)

Mercury and Door-to-Door Modelling

Mercury

- Gate-to-gate modelling expanded to multimodal journeys
- Stochastic, agent-based model (representing main elements of ATM system) at individual flight and passenger level
- Capturing European-wide network effects; non-linearities between delay for flights and passengers due to missed connections

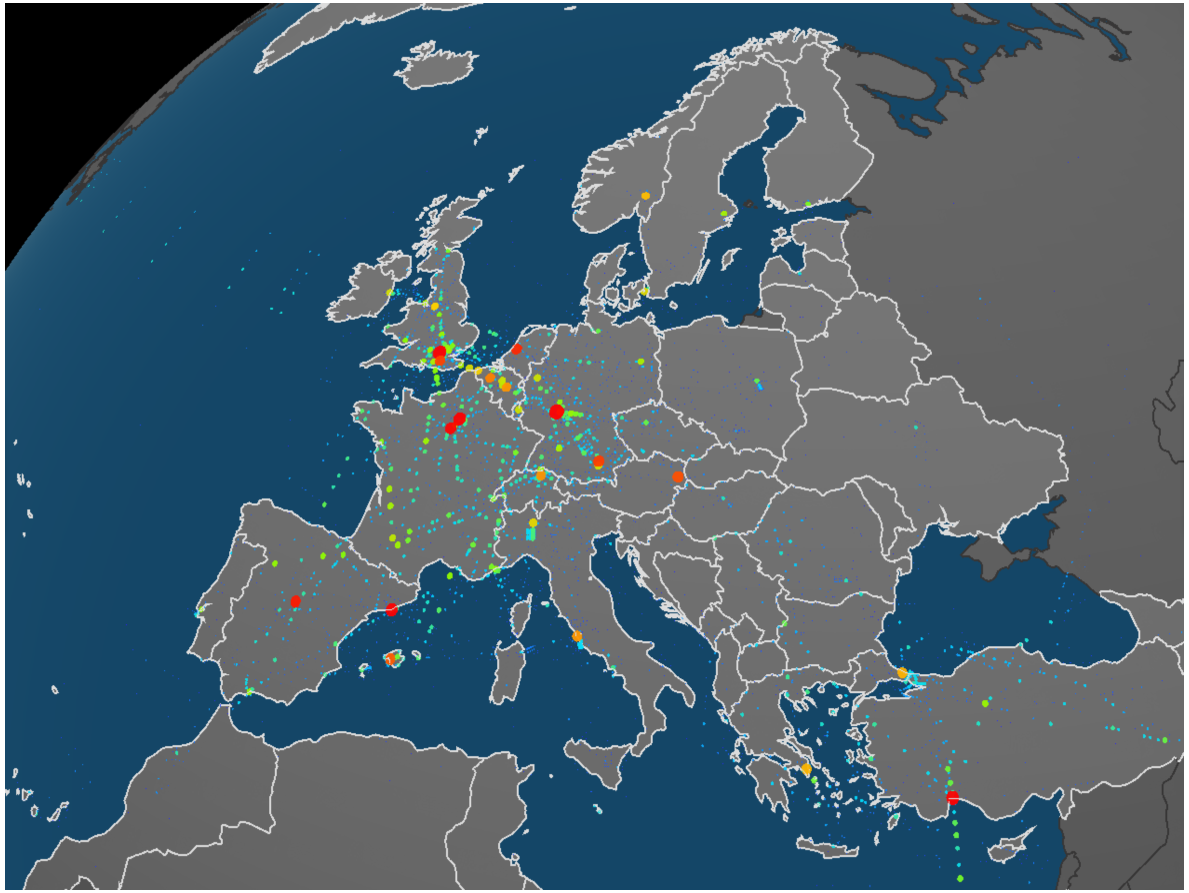
First and last mile modelling

- D2D model to combine outcome of different trip segments

Door-to-door flight segment	Door-to-door rail segment
Door-to-kerb (D2K)	Door-to-platform
Kerb-to-gate (K2G)	
Gate-to-gate (G2G)	Platform-to-platform
Gate-to-kerb (G2K)	
Kerb-to-door (K2D)	Platform-to-door
Multimodal segments	
Gate-to-platform (G2P)	
Platform-to-gate (P2G)	
Kerb-to-platform (K2P)	
Platform-to-kerb (P2K)	

R-NEST modelling & air network performances

To evaluate the ***impact of future high-speed train*** *development over air traffic demand and ATM* ***network performances*** *in the 2040 time horizon.*



The Modelling Approach

Modus sesar JOINT UNDERTAKING

1

Model Calibration

- Updated Delay Model

2

Future Traffic (2040)

- 2040 reference Forecast
- MODUS 2040 forecast with HSR impact

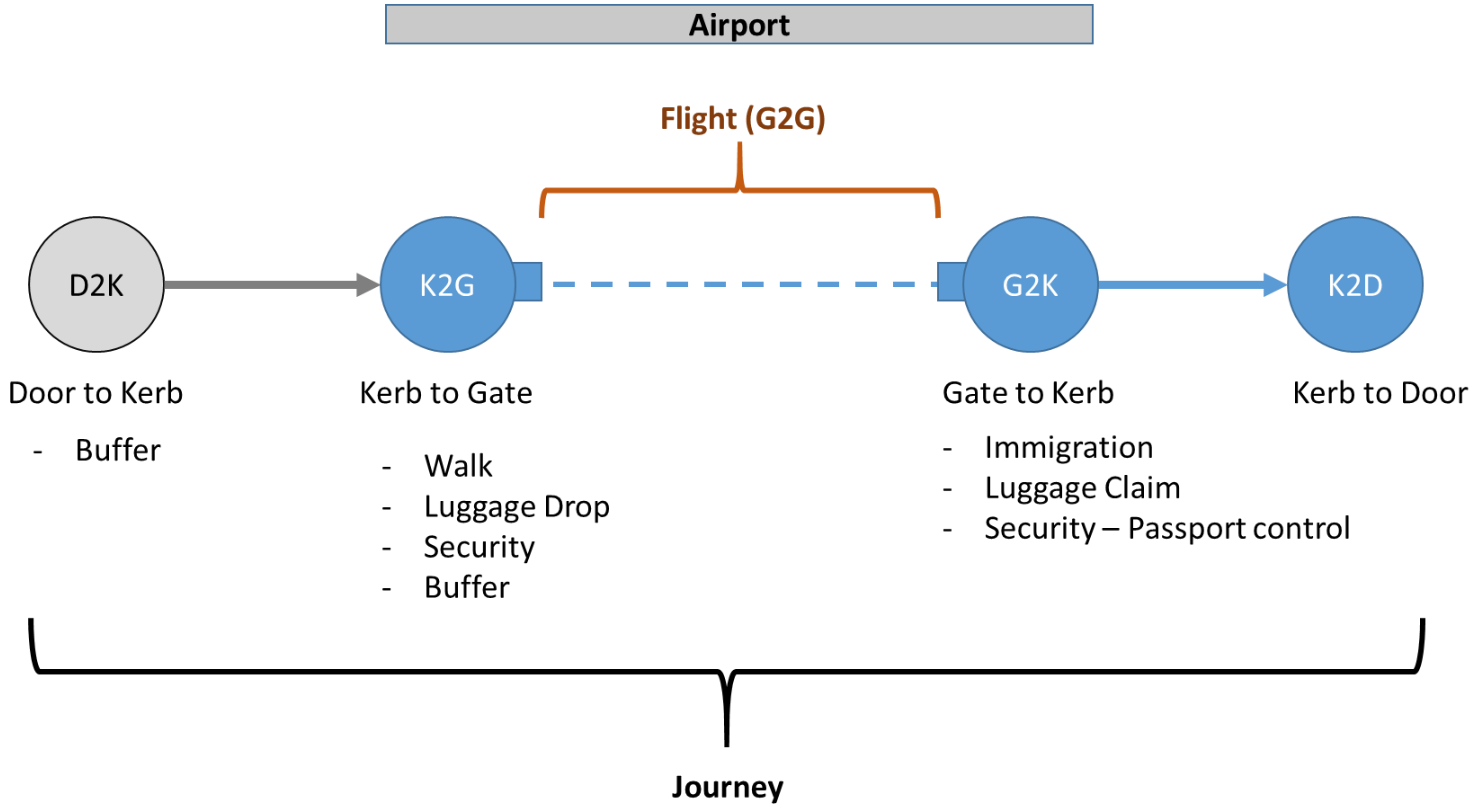
3

Perf. Assessment

- Impacted flight demand (HSR)
- ATM Delay

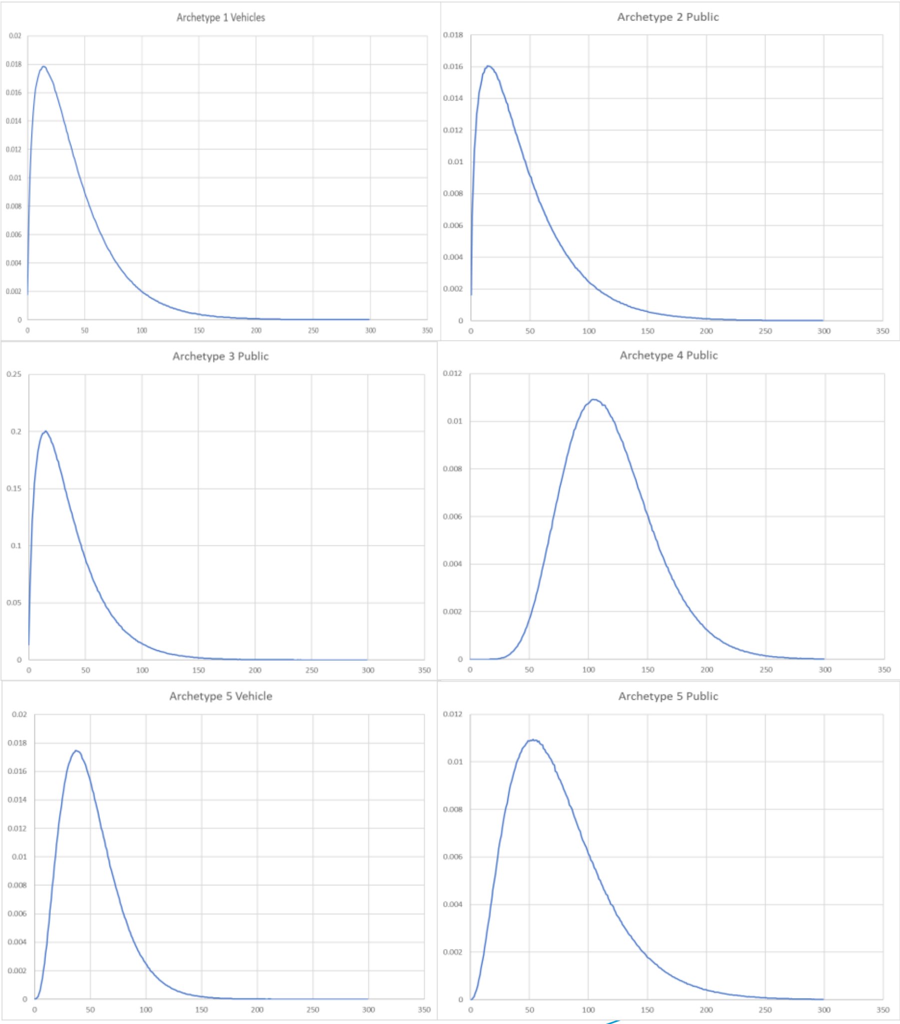
The air passenger journey in R-NEST (1/2)

- **Passenger journey** model introduced in R-NEST
  - ✓ From Door to Door
- All phases are modelled
  - ✓ **Door to Kerb (D2K)**: moving to the airport (by car or public transport)
  - ✓ **Kerb to Gate (K2G)**: sequence within the airport
  - ✓ **Gate to Gate (G2G)**: the flight
  - ✓ **Gate to Kerb (G2K)**: to exit the airport
  - ✓ **Kerb to Door (K2D)**: from the airport to the final destination



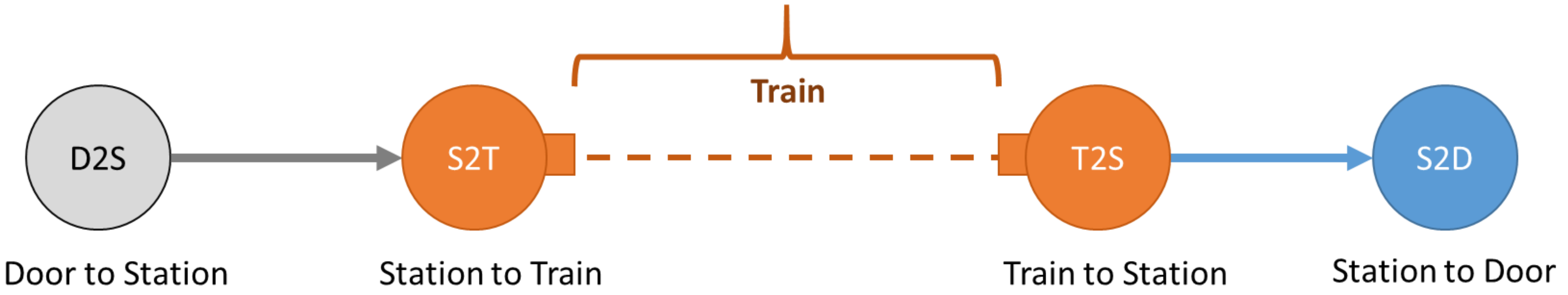
The air passenger journey in R-NEST (2/2)

- Generic model to compute travel time (probabilistic function)
  - ✓ From home to airport
  - ✓ From airport to final destination
- Based on city & airport archetype defined in Modus project
- Passenger travel preferences:
  - ➢ 80% public transport
  - ➢ 20% vehicles



Modus – A simple rail itinerary model

- A simple rail model introduced in R-NEST for Modus
- Similar to the air passenger journey model



- Parameters (average values):
  - Door to Station & reverse **(D2S, S2D)**: **45 min**
  - Station to Train **(S2T)**: **30 min**
  - Train to Station **(T2S)**: **20 min**

Multimodal Experiments

- *R-NEST*

<table>
<tr><th>Baseline</th><th>Reference</th><th>Modus</th><th>Modus Air & Rail assumptions</th></tr>
<tr><td rowspan="4">#1
2019 baseline</td><td rowspan="2">#2
2040 most-likely future (base traffic growth)</td><td>#2.1
(Short-haul ban)</td><td>• 2040 most-likely scenario traffic level minus shifted air demand to rail on routes less than 500 km in Germany, France, Spain and Italy
• No en-route issue due to lack of capacity (SESAR)</td></tr>
<tr><td>#2.2
(Short-haul ban & Travel Time Competition)</td><td>• 2040 most-likely scenario traffic level minus shifted air demand to rail on routes:
✓ Less than 500 km in Germany, France, Spain and Italy and minus
✓ With air/rail competition and routes with lower Door to Door travel time for rail
• No en-route issue due to lack of capacity (SESAR)</td></tr>
<tr><td rowspan="2">#3
2040 High (high traffic growth)</td><td>#3.1
(Short-haul ban)</td><td>• 2040 most-likely scenario traffic level minus shifted air demand to rail on routes less than 500 km in Germany, France, Spain and Italy
• No en-route issue due to lack of capacity (SESAR)</td></tr>
<tr><td>#3.2
(Short-haul ban & Travel Time Competition)</td><td>• 2040 most-likely scenario traffic level minus shifted air demand to rail on routes:
✓ Less than 500 km in Germany, France, Spain and Italy and minus
✓ With air/rail competition and routes with lower Door to Door travel time for rail
• No en-route issue due to lack of capacity (SESAR)</td></tr>
</table>

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Multimodal Experiments

- *Mercury*

Experiment	Air layer[1]	Rail layer
1. Current baseline	Air traffic and passenger itineraries for 2019	Rail traffic 2019
2a. Future baseline	Air traffic and passenger itineraries for 2040 regulated growth	Rail infrastructure and traffic for 2040
2b. Short-haul ban	Air traffic and passenger itineraries for 2040 regulated growth, removing flights less than 500km in France, Germany, Italy, Spain	Rail infrastructure and traffic for 2040
3a. Future high growth (with technology)	Air traffic and passenger itineraries for 2040 global growth	Rail infrastructure and traffic for 2040

[1]The air traffic and passenger demand are grown based on the Regulation and Growth and Global Growth forecasts from EUROCONTROL's Challenges of Growth forecast.

Modelling Assumptions for Mercury & R-NEST

Feature	Mercury	R-NEST
Scenarios	▪ Baseline 2019 & 2040 ▪ Short-haul ban 2040 in Italy, France, Germany, Spain <500 Km ▪ Significant growth with strong technological support2040	
		▪ Short-haul ban & rail competition (travel time reduction) 2040 ▪ High traffic growth & rail competition (travel time reduction) 2040
Period modelled	Busy September day: 2019, 2040	1st August-30th September: 2019, 2040
Inclusion of explicit passenger Itineraries	Yes	No

Air layer	▪ Initial flows from 2014
	▪ *2018-Challenges of Growth*
	  ▪ *Scope 2040*
	  ▪ Experiments 2 increase by 53%
	  ▪ Experiments 3 increase by 84%
		▪ Initial flows 61 days from 1st August 2019
		▪ *2022-Aviation Outlook*
		  ▪ *Scope 2050*
		  ▪ Experiments 2 increase by 25%
		  ▪ Experiments 3 increase by 51%

Higher resolution airspace	No	Yes
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 are 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 is ceased in case of >=20% pax switch to rail

Mercury Results

Mercury Results (1 of 3) Traffic and passenger flows with D2D averages

Exp. #	Description	Disruption	Air	Rail	Key metrics				
					Flights	Air pax¶	Pax S2R Cancelled pax	Network D2D average¶	Short-haul ban states D2D average† ¶
1	Current baseline	×	2019 traffic	2019 network	**31 080**	**4 029 k** *1 950 k*	-	*467 mins* ≈	*422 mins* ≈
2a	Future baseline	×	2040 base growth	2040 network	**44 900**	**5 920 k** *2 720 k*	-	*469 mins*	*424 mins*
2b	2a + short-haul ban†	×			**1360 banned**	*110 k* banned	= *110* k *1.6* k‡	*445 mins* ≈	*402 mins* ≈
3a	Future high growth	×	2040 high growth		**52 200**	**7 190 k** *3 220 k*	-	*439 mins*	*394 mins*

† Values in this row/col refer to the four countries in which the short-haul ban is applied (GCD < 500 km not operated by air in DE/FR/ES/IT, *where rail alternatives exist*)

¶ Values in italics refer to passengers travelling on the OD pairs within the 176 European airports for which Modus applied city/airport archetypes

‡ Cancelled due to exceptional circumstances, e.g. substitute air-rail-air itineraries being impractical

Mercury Results (2 of 3) Passenger flows with G2G CO_2 and flight waits

Exp. #	Description	Disruption	Air	Rail	Key metrics				
					Air pax¶	G2G network CO_2	G2G short-haul ban states CO_2 †	Network flight wait	Short-haul ban states flight wait †
1	Current baseline	×	2019 traffic	2019 network	**4 029 k** *1 950 k*	94 kg/pax	99 kg/pax	149 mins	122 mins
2a	Future baseline	×	2040 base growth	2040 network	**5 920 k** *2 720 k*	86 kg/pax	91 kg/pax	133 mins	112 mins
2b	2a + short-haul ban†	×			*110 k* banned	87 kg/pax	92 kg/pax	137 mins	112 mins
3a	Future high growth	×	2040 high growth		**7 190 k** *3 220 k*	85 kg/pax	89 kg/pax	125 mins	101 mins

† Values in this row/col refer to the four countries in which the short-haul ban is applied (GCD < 500 km not operated by air in DE/FR/ES/IT, *where rail alternatives exist*)
¶ Values in italics refer to passengers travelling on the OD pairs within the 176 European airports for which Modus applied city/airport archetypes

Mercury Results (3 of 3) Disruption flows with cancelled pax and CO_2 saved

Exp. #	Description	Disruption	Air	Rail	Key metrics				
					Flights cancelled	Air pax cancelled	Pax S2R	Cancelled pax	CO_2 saved
1*	Current baseline	✓	2019 traffic	2019 network	898	69.8 k	**4.81 k**	**93 %**	20 kg/pax
2a*	Future baseline	✓	2040 base growth	2040 network	1460	104 k	**7.27 k**	**93 %**	19 kg/pax
2b*	2a + short-haul ban†	✓			1170	95 k	**3.14 k**	**97 %**	20 kg/pax
3a*	Future high growth	✓	2040 high growth		1530	122 k	**17.5 k**	**86 %**	18 kg/pax

* These experiments are subject to disruption.

† Values in this row refer to the four countries in which the short-haul ban is applied (GCD < 500 km not operated by air in DE/FR/ES/IT, *where rail alternatives exist*)

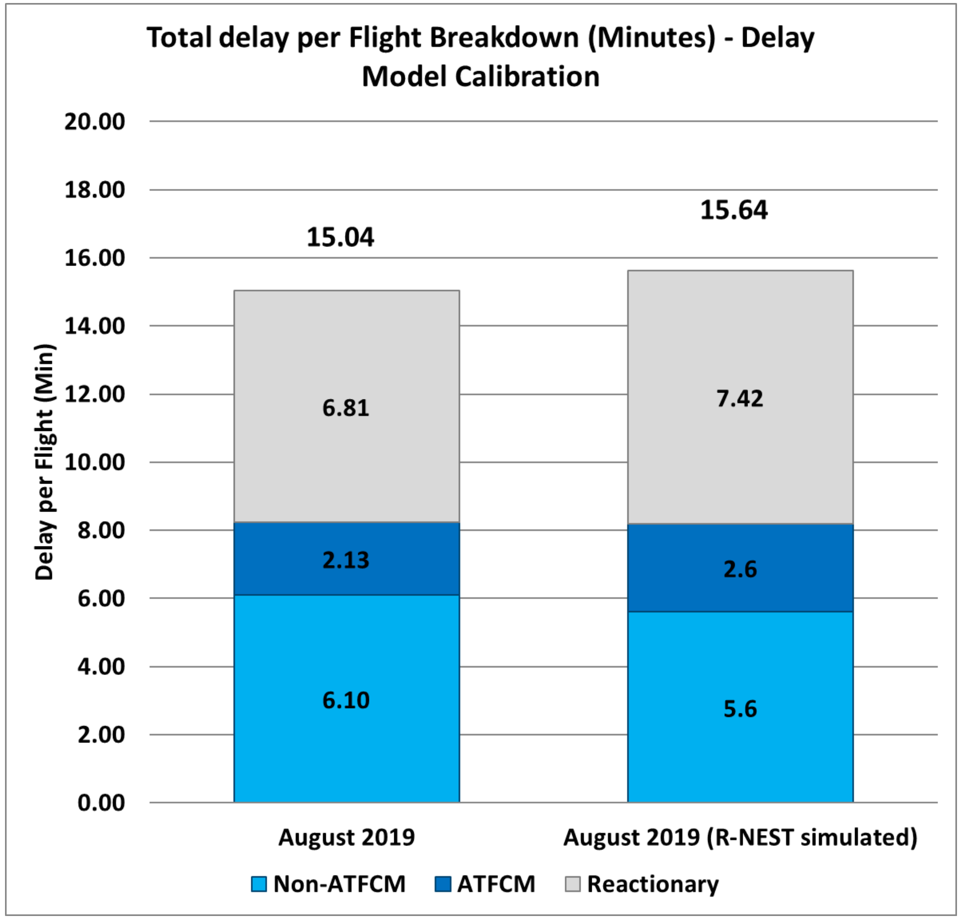
R-NEST Results

Delay modelling & 2040 Network situation

R-NEST – 2019 Delay Model Calibration

- STATFOR CODA data from August 2019 used as reference (full month).
- Results from Calibration in line with values observed in August 2019.
- Agv delay of **15,64 min per flight** (All causes) vs **15.04** min per flight in 08/2019.

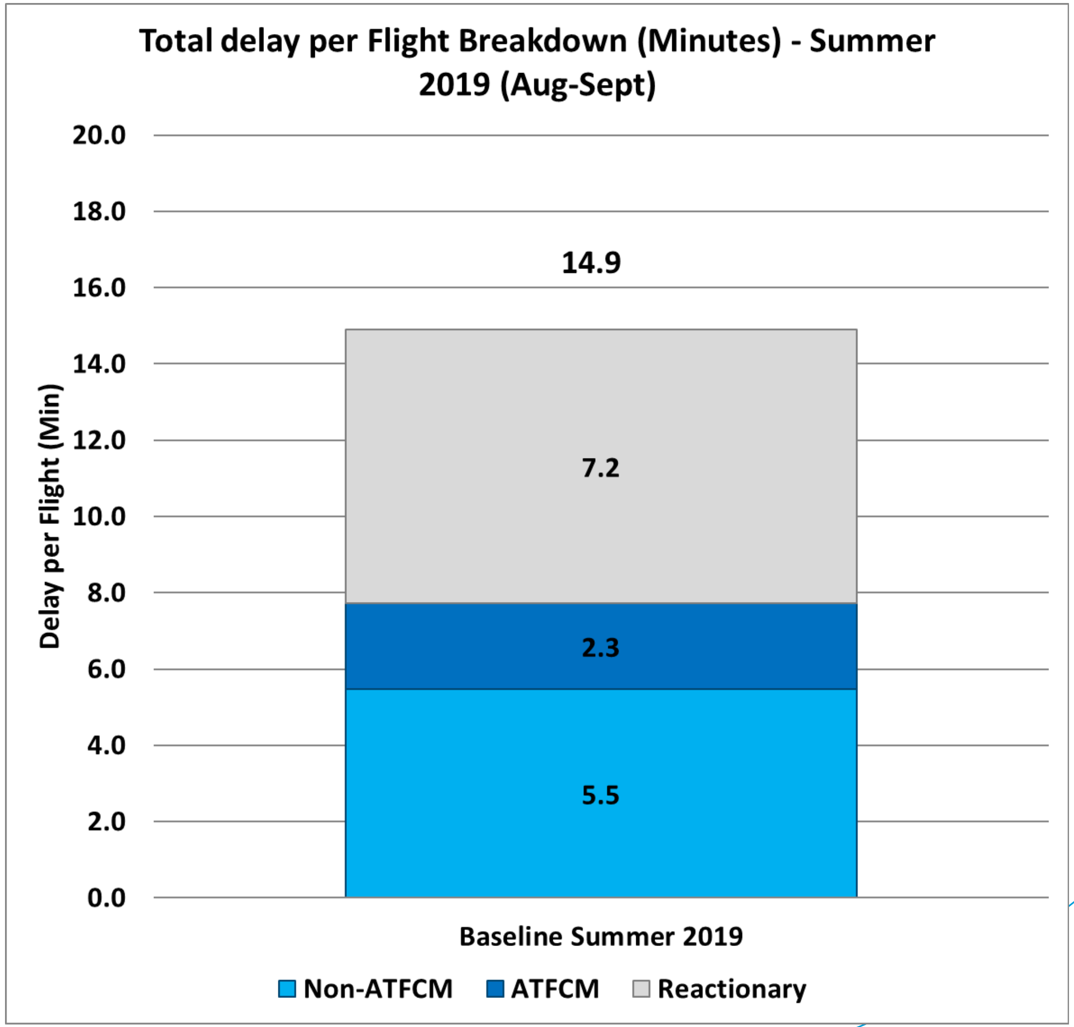
Delay Model Calibration - Simulated Delays (All causes) August 2019		
August 2019 Daily Flight demand	35085	
	Average Daily Delay (min)	**Average Delay by Flight (min)**
Reactionary	260184	**7.42**
ATFCM	92307	**2.63**
Non-ATFCM	196100	**5.59**
Total Delay	513591	**15.64**



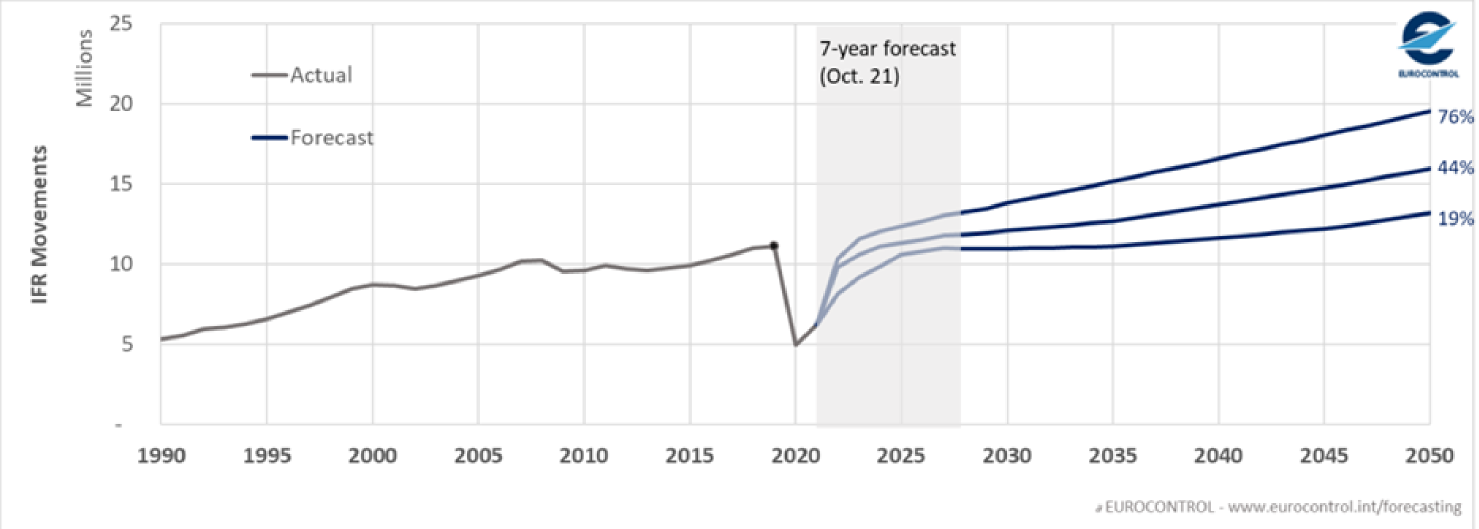
2019 – Baseline scenario (Delay)

- 61 days of traffic used as baseline scenario
- Traffic data from summer 2019 used as input (from 1st August to 30th September).
- Simulated network situation:
  - ✓ Avg delay of **14.9 min per flight** (All Causes) .

Summer 2019 - Baseline Delays (All Causes)		
2019 Daily Flight demand	34841	
	Average Daily Delay (min)	**Average Delay by Flight (min)**
Reactionary	249877	**7.17**
ATFCM	78749	**2.26**
Non-ATFCM	190514	**5.47**
Total Delay	519140	**14.9**



2040 – Future demand evolution (1/2)



ECAC	IFR Flights						
	2019		2050			2050/2019	
	Total (million)	Avg. daily (thousands)	Total (million)	Avg. daily (thousands)	Extra flights/day (thousands)	Total growth	AAGR
***High* scenario**	11.1	30.4	19.6	53.6	23.2	+76%	+1.8%
***Base* scenario**			16.0	43.7	13.4	+44%	+1.2%
***Low* scenario**			13.2	36.2	5.8	+19%	+0.6%

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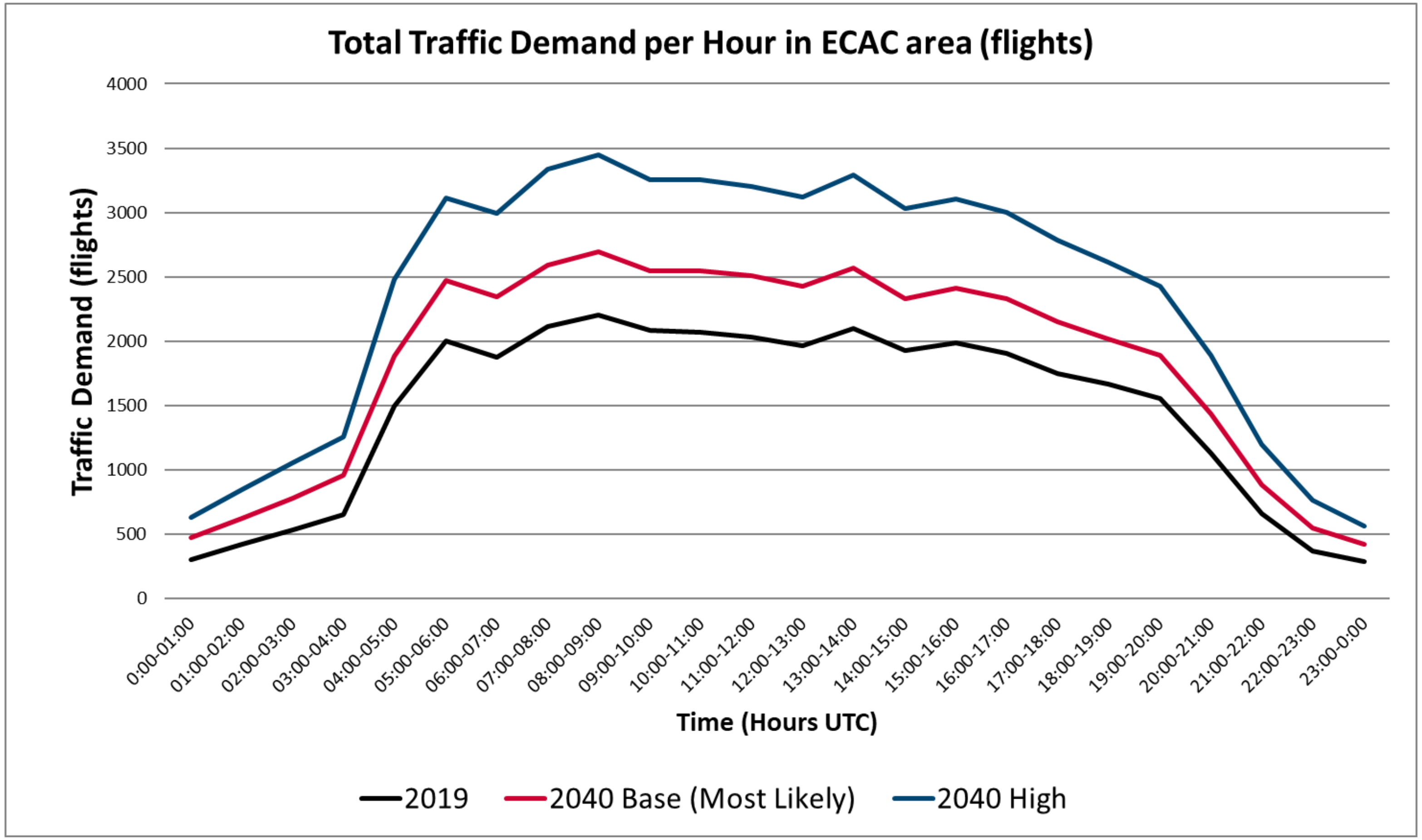
- Based on last EUROCONTROL aviation outlook 2050 (April 2022)

2040 – Future demand evolution (2/2)



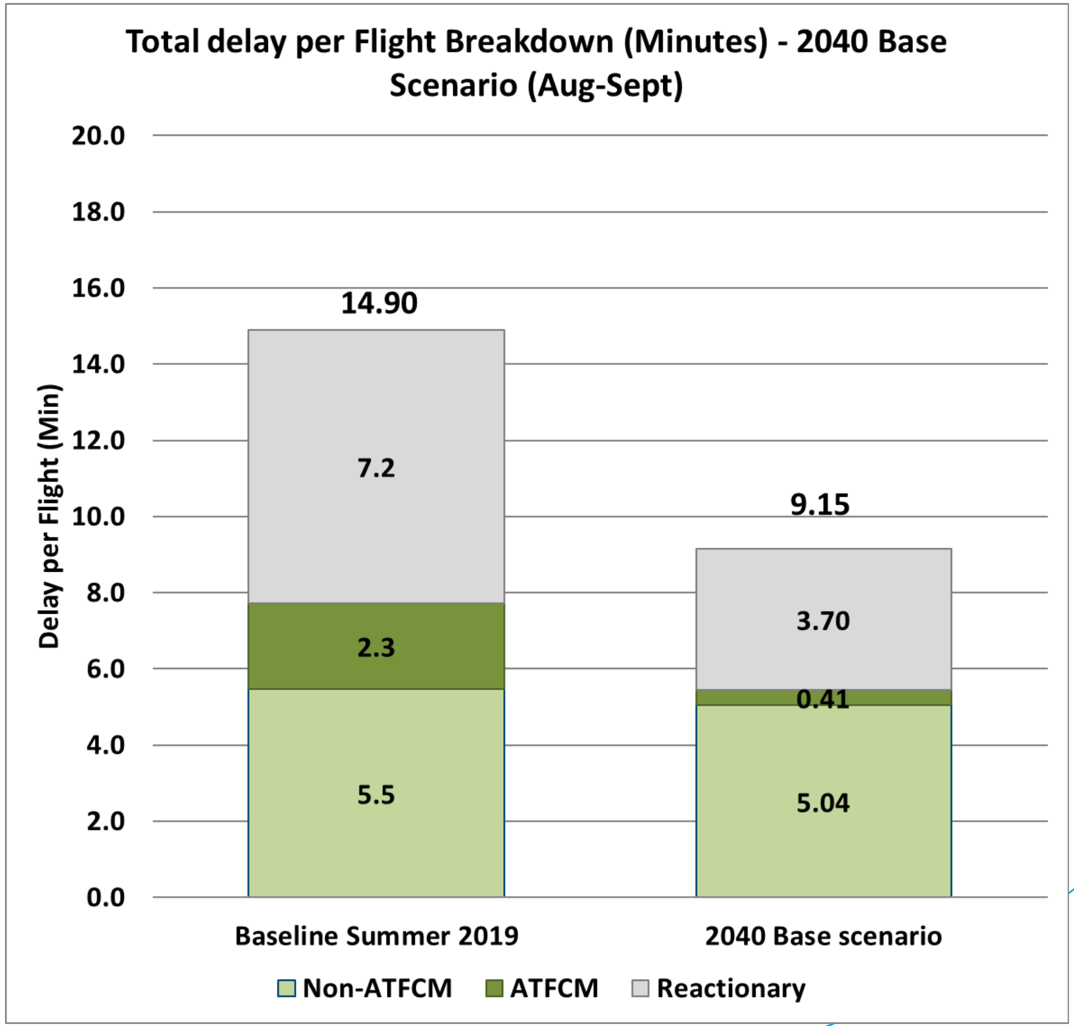
	Average Daily demand (flights)	
2019 (August - September)	34841	
FORECAST SCENARIO	Constrained Forecast	Growth (%)
2040 - Base (Most Likely)	43539	25%
2040 - High	52723	51%

- Post COVID-19 crisis forecast shows lower expected demand compared to last Challenges of Growth 2018 (CG18) study.

2040 – Base scenario (Delays)

- Average daily demand of **43539 flights**.
- Network simulations show that **in 2040, Airport capacity is enough to cope with the expected demand growth** regarding the Base scenario forecast (i.e. Most-Likely).
- Delay situation is improved compared to 2019, with a reduction in the average total delay per flight, including ATFCM and reactionary delays, **from around 15 minutes down to around 9 minutes per flight**.

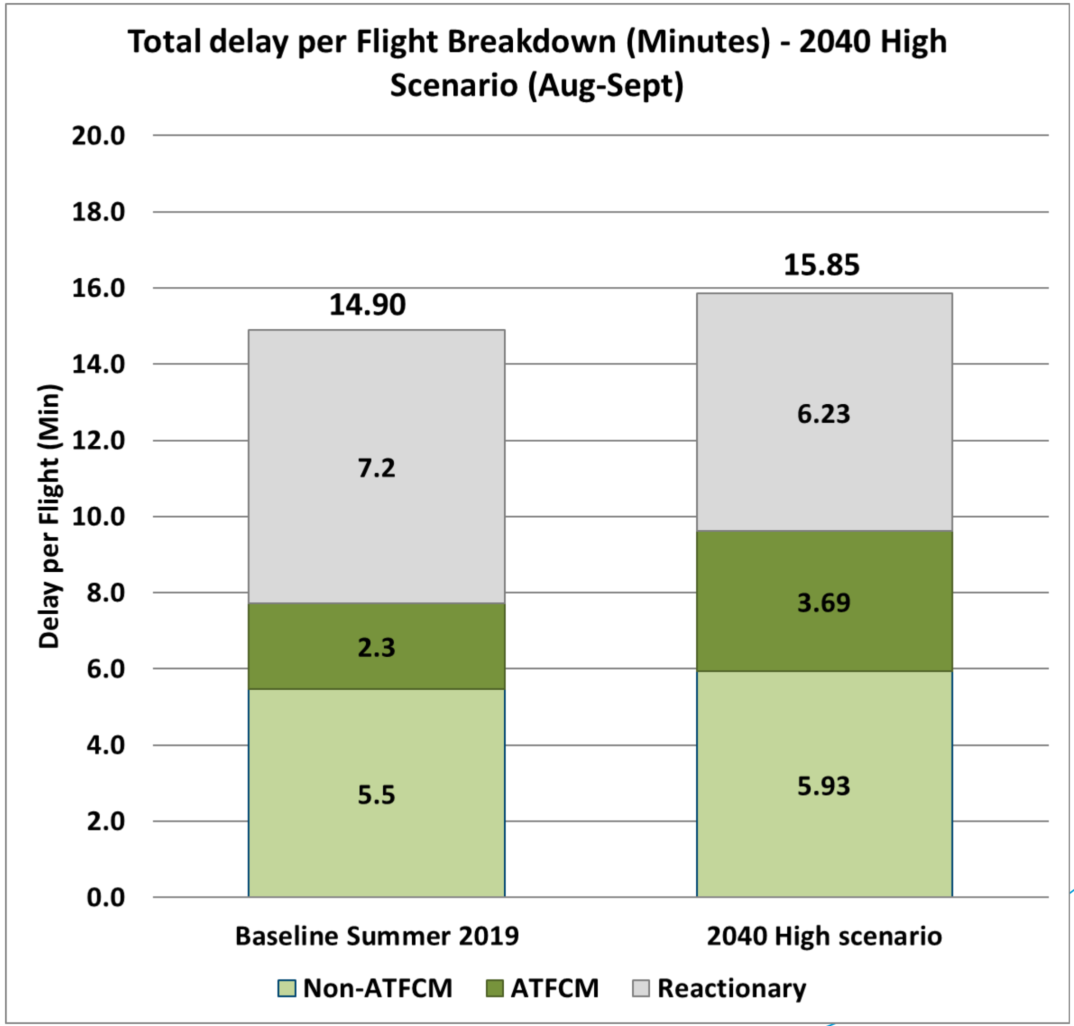
Summer 2040 – Base Scenario Delays (All Causes)		
2040 Base Daily Flight demand	43539	
	Average Daily Delay (min)	**Average Delay by Flight (min)**
Reactionary	161106	**3.70**
ATFCM	17997	**0.41**
Non-ATFCM	219404	**5.04**
Total Delay	398507	**9.15**



2040 – High scenario (Delays)

- Average daily demand of **52723 flights**.
- Network simulations show that **in 2040,** in the High scenario forecast, **Airport capacity is showing limits to cope with the expected demand growth**.
- Delay situation climb up to level of delays greater than the one observed in 2019. With an increase in the average total delay per flight, including ATFCM and reactionary delays, **from around 15 minutes up to around 16 minutes per flight**.

Summer 2040 – High Scenario Delays (All Causes)		
2040 High Daily Flight demand	52723	
	Average Daily Delay (min)	**Average Delay by Flight (min)**
Reactionary	329014	**6.23**
ATFCM	194748	**3.69**
Non-ATFCM	312456	**5.93**
Total Delay	836218	**15.85**

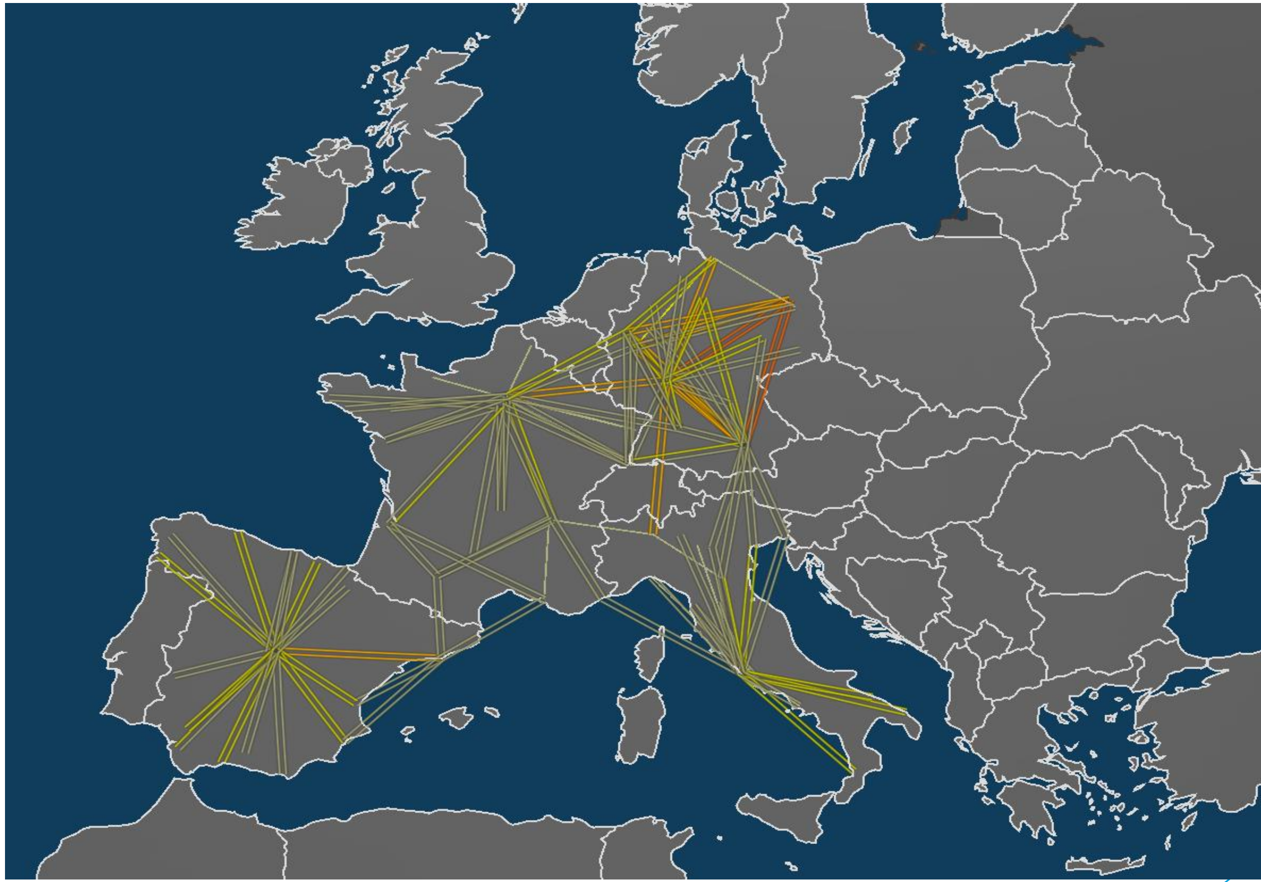


Modus – Flight ban policy in R-NEST

2040 – Flight ban policy (Ban)

- Ban policy for flights below 500 Km
  - ➢ Orthodromic distance
  - ➢ Limited to :
    - ✓ **City-pairs with Air-Rail competition**
    - ✓ **In France, Germany, Italy & Spain**

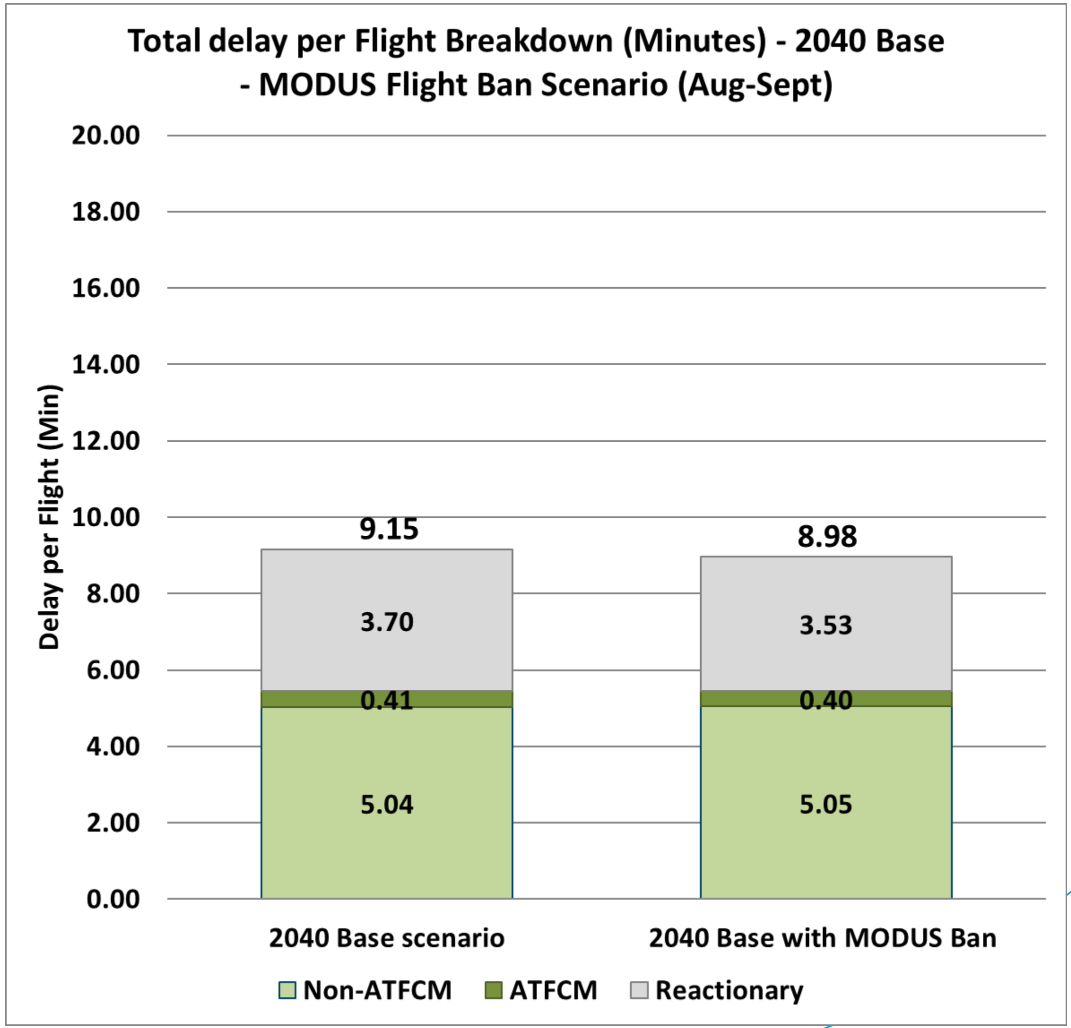
- **~2%** of air traffic demand moved to rail network (ECAC level)
  - ➢ **Base Forecast: ~1000** flights per day
  - ➢ **High Forecast: ~1200** flights per day



2040 Base – Modus ban scenario (Delays)

- Average daily demand of **42610 flights**.
- **2.1%** reduction in traffic demand
- Flight **ban policy** for medium haul flights below 500 km **reduces** the **average network daily demand by around 1000 flights**
- The combinaison of enough airport capacity and a lower traffic demand results in **slightly lower delays**:
  - ✓ From average per flight of 9.1 min down to 8.98 min
  - ✓ **~10%** reduction in ATFCM delays
  - ✓ **~3%** reduction in Total delays (All Causes)

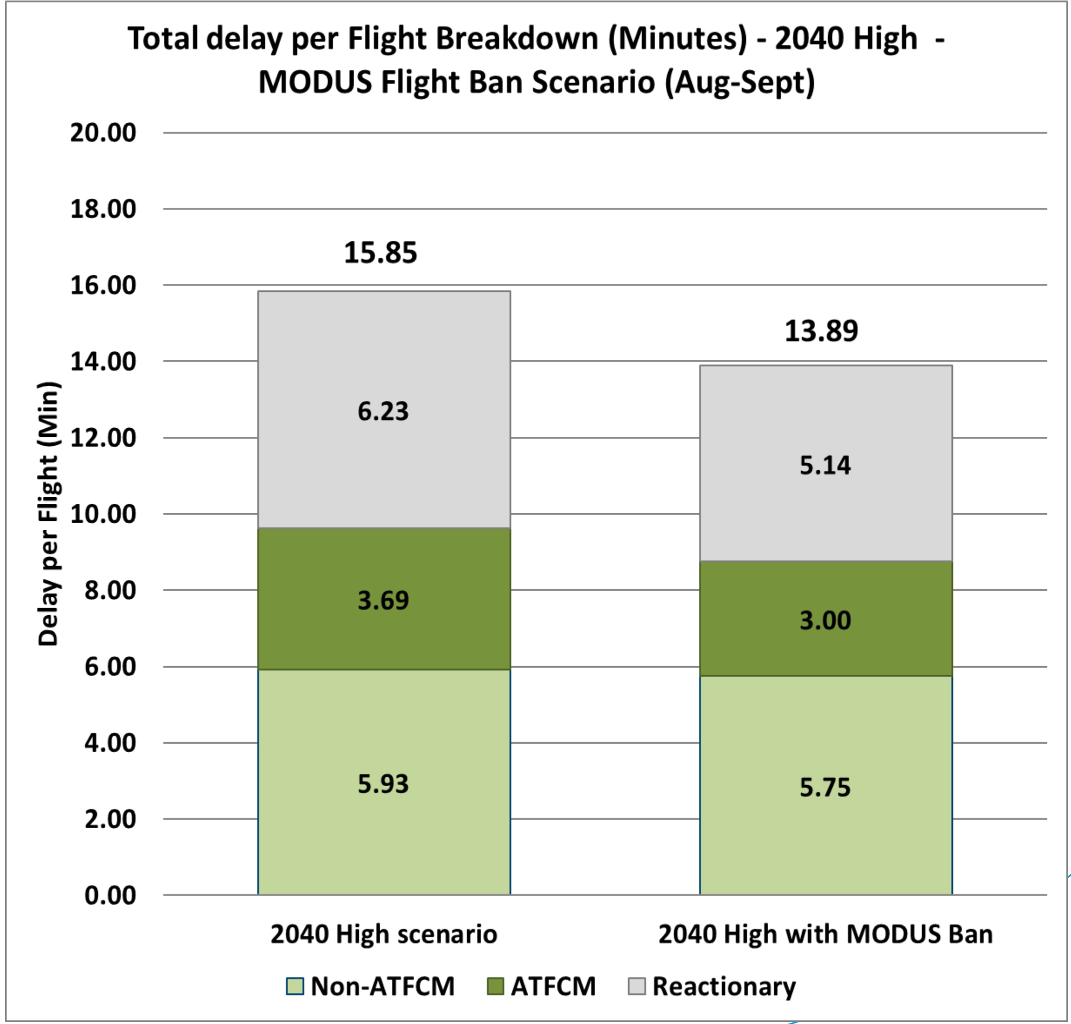
Summer 2040 Base – Modus Flight Ban Delays (All Causes)		
Modus Ban daily demand	42610	
	Average Daily Delay (min)	Average Delay by Flight (min)
Reactionary	150621	**3.53**
ATFCM	16881	**0.40**
Non-ATFCM	215144	**5.05**
Total Delay	382647	**8.98**



2040 High – Modus ban scenario (Delays)

- Average daily demand of **51461 flights**.
- **2.3%** reduction in traffic demand
- Flight **ban policy** (i.e. flights below 500 km) **reduces** more the **average network daily demand with 1260 flights** against around 1000 flights in the 2040 Base scenario.
- Average delay per flight down to **13.89 min** from **15.85 min**, a **12.4%** reduction.
- With the high level of demand on the main airports, moving the flights to rail reduces significantly, the ATFCM and reactionary delays.

Summer 2040 Base – Modus Flight Ban Delays (All Causes)		
Modus Ban daily demand	51461	
	Average Daily Delay (min)	**Average Delay by Flight (min)**
Reactionary	265266	**5.14**
ATFCM	154684	**3.00**
Non-ATFCM	295758	**5.75**
Total Delay	715708	**13.89**

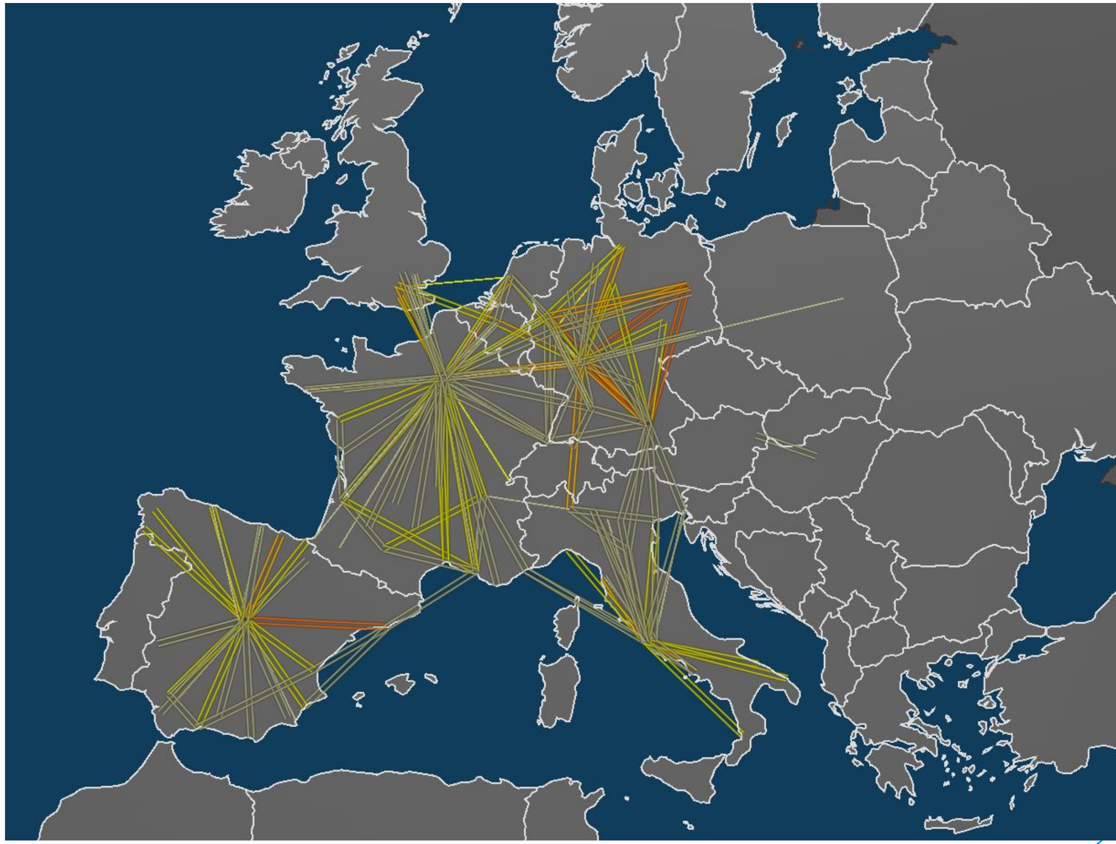


Modus – Flight ban policy & travel time competition

Modus – Ban & travel time competition in 2040

- Ban policy for flights below 500 Km (orthodromic distance & Limited to **city-pairs with Air-Rail competition**)

- Air/Rail travel time competition model
  - ➢ Based on passenger travel journey model
  - ➢ Travel time (D2D) evaluated for all flight's passengers with rail competition
    - ✓ Time travel computed for both air & rail transport mode
    - ✓ Flight Passenger switch to rail when 1h travel time benefit observed in rail vs air travel mode.
    - ✓ Flight transferred to rail when 20% of passengers move to rail



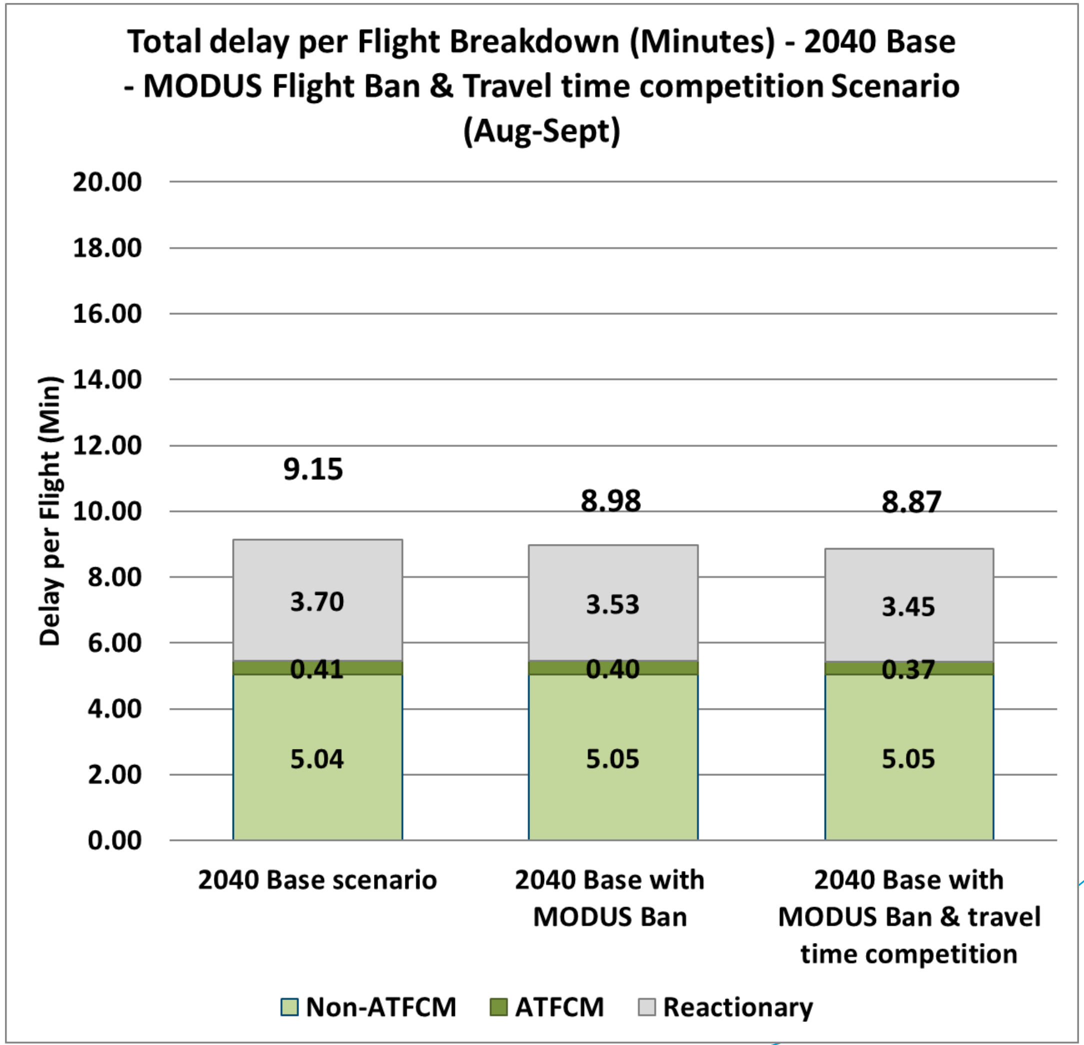
- Results:
  - ➢ **2040 Base scenario: 3%** Traffic decrease (ECAC level) & **~1500** flights per day moved to rail
  - ➢ **2040 High scenario: 3%** Traffic decrease (ECAC level) & **~1600** flights per day moved to rail

2040 Base – Modus (Ban & travel time)

Modus sesar JOINT UNDERTAKING

- Average daily demand of **42090 flights**.
- **~3%** reduction in traffic demand
- Flight **ban policy & Itineraries** for medium haul flights below 500 km **reduces** the **average network daily demand by around 1500 flights**
- The combinaison of enough airport capacity and a lower traffic demand results in **slightly lower delays**:
  - ✓ From average per flight of 9.1 min down to 8.87 min
  - ✓ ~13% reduction in ATFCM delays
  - ✓ ~6% reduction in Total delays (All Causes)

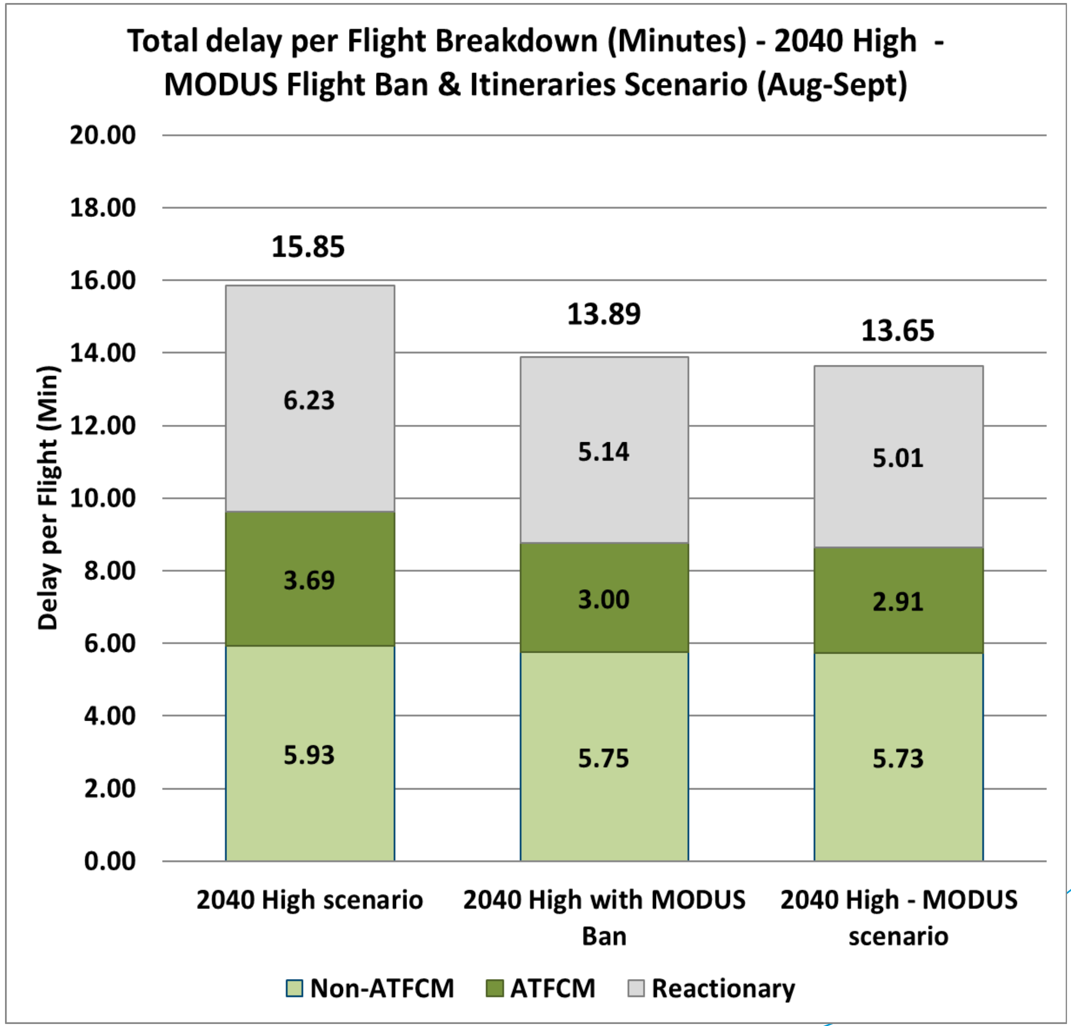
Summer 2040 Base – Modus Flight Ban & Itineraries Delays (All Causes)		
Modus Ban & Itineraries daily demand	42090	
	Average Daily Delay (min)	Average Delay by Flight (min)
Reactionary	145283	**3.45**
ATFCM	15663	**0.37**
Non-ATFCM	212599	**5.05**
Total Delay	373547	**8.87**



2040 High – Modus (Ban & travel time)

- Average daily demand of **51141 flights**.
- **~3%** reduction in traffic demand
- Flight **ban policy & Itineraries** for medium haul flights below 500 km **reduces** the **average network daily demand by around 1600 flights**
- The combinaison of enough airport capacity and a lower traffic demand results in **slightly lower delays**:
  - ✓ Average delay per flight **down to 13.65 min from 15.85 min**
  - ✓ **~23%** reduction in ATFCM delays
  - ✓ **~15%** reduction in Total delays (All Causes)

Summer 2040 High – Modus Flight Ban & Itineraries Delays (All Causes)		
Modus Ban & Itineraries daily demand	51141	
	Average Daily Delay (min)	Average Delay by Flight (min)
Reactionary	265266	**5.01**
ATFCM	148957	**2.91**
Non-ATFCM	293277	**5.73**
Total Delay	699202	**13.65**



Summary of R-NEST Results

- **+25%** - expected traffic growth up to 2040 in the most-likely scenario, **+51%** in high scenario

- Network performance simulations show that **in 2040, Airport capacity is enough to cope with the expected demand growth** regarding the Base scenario forecast (i.e. Most-Likely).

- Shift to rails move between **2%** and **3%** of the expected air demand in 2040.

- Impact analysis in network performances shows **reduction in ATFCM delays** ranging fom **10% in the short-haul ban scenario** (most-like growth) **up to 23% in the highest traffic growth** scenario associating short-haul ban and air/rail travel time competition.

Lessons learned

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

JOINT UNDERTAKING

Modus

Enablers and Barriers | Recommendations

Modus Consortium

Final Disseminatin Event | Online | 27th January 2023

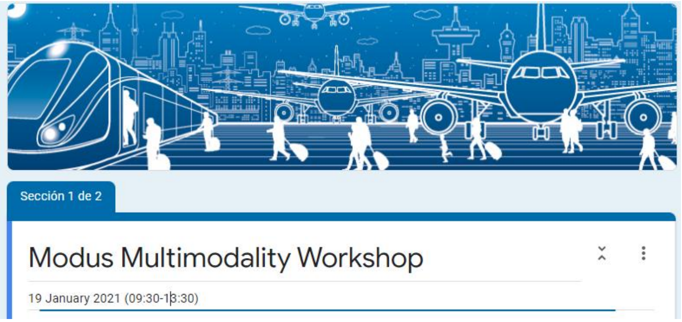
EUROPEAN PARTNERSHIP

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.

Co-funded by the European Union

Modus workshop on “The future of multimodal transport: Horizon 2040” 19.01.2021

The first Modus workshop: The Future of Multimodal Transport: Horizon 2040 was held online on 19 January, attended by almost 90 experts, mainly from the air and rail sectors.

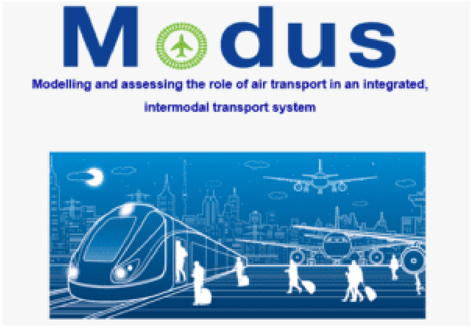


The workshop was divided into two parts:

- first session with a focus on multimodality objectives and future scenarios.
- second interactive part focusing on multimodality enablers, followed by a final session to share results and conclusions amongst all the participants.

Modus workshop on “What could future air-rail multimodal mobility look like?” 14.02.2022

More than 170 participants registered for the online second Modus workshop, which brought together experts from the air and rail sectors.

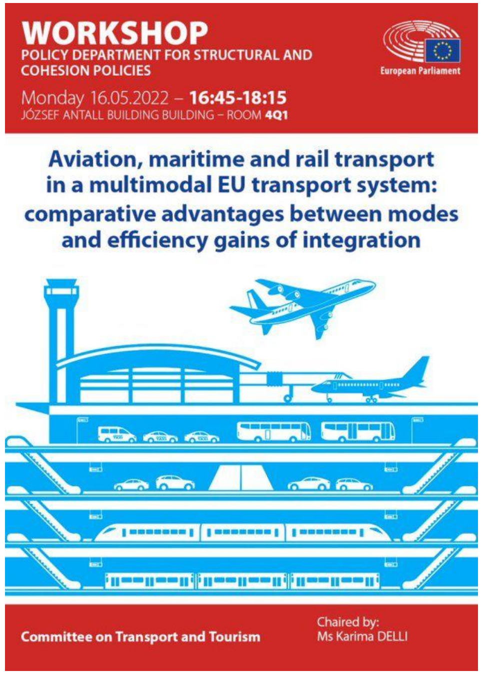


"What could future air-rail multimodal mobility look like?"

- The main objective of the workshop was to discuss ideas from participants on what models need to include in order to be useful to a range of stakeholders. What was Modus doing well, and what is missing?
- Two lively discussion roundtables with industry stakeholders and interactive boards for participants were organised about Modus Scenarios and Use Cases.

Stakeholder Engagement and Dissemination

Modus sesar JOINT UNDERTAKING



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LISBON 2022

50TH EUROPEAN TRANSPORT CONFERENCE 2022

Symposium Nachhaltige Luftfahrt
Der Weg bis 2050
Am 3. November 2022 in Hamburg

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Nov 17 12:15
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Modus scenarios for the future of multimodal (air plus rail) transport
Sustainability

- The evolution of passenger demand for multimodal mobility;
- How air-rail complementarity can improve passenger experience; and
- Transport performance and sustainability

Vanessa Perez,
Senior Advisor Passenger Department And Latin America Region,
U.I.C. International Union of Railways

WORLD PASSENGER FESTIVAL

Where Do We Go From Here?

Requirements for a multimodal system

- 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)

Where Do We Go From Here?

Enablers of a multimodal system

- Legislation and a regulatory framework to 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 (informed decision making for policy makers and travelers).
- Smart travel: data availability and sharing, the avoidance of disruptions, and/or the dynamic rescheduling of journeys.
- Data and platformatisation *(e.g.*, investments in innovative ideas) to develop a true D2D travel application for travellers.
- Infrastructure investments for enhanced integration of different modes along the travel chain

Conclusions and Next Steps

Modus Consortium
Final Disseminatin Event | Online | 27th January 2023

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Summary and Conclusions

Thank you for joining our dissemination event today and engaging in discussions with the Modus team!

Further Research

Advancement in modelling

- Integration of these models with a multimodal performance framework.
- Multimodal evaluation tool (*e.g.*, quantifying new policy impacts, assessment for implementation).
- Further development of airside model to generate flows and itineraries specific to each modelled scenarios.
- Further development of the passenger mobility models to take into account the rail layer as part of multimodality.

Multimodal mobility research

- Enhanced analysis of passenger mobility behaviour to assess future modal choices.
- Opportunities of enhanced, joint air-rail mobility in Europe.
- Door-to-door mobility connections and regional characteristics.
- Improvement of data accessibility and sharing as well as the development of feasible prototypes and sustainable business solutions.

If you have any questions or like to learn more about Modus, contact us via:

Modus Website: https://modus-project.eu/

Modus Twitter: @Modus_project

Modus LinkedIn:
https://www.linkedin.com/company/moduseuproject/

All results presented today are available at https://modus-project.eu/