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Abstract

Scenario definition aims to identify and characterise current and future scenarios for long-distance passenger multimodal transport in Europe, which will set the context for the implementation and evaluation of the MultiModX Solutions. A scenario corresponds to a particular operational environment for multimodal transport today or in the future. A scenario is defined by a set of passenger archetypes, a regional context, relevant strategic and/or tactical policies, expected demand and supply levels, and certain disruptions. This document details these components and the scenarios to be used to evaluate the solutions.

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Authoring & approval

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MultiModX

INTEGRATED PASSENGER-CENTRIC PLANNING OF MULTIMODAL NETWORKS

MultiModX

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1 Executive summary

Scenario definition **addresses Objectives 1 of the project** as stated by the Grant Agreement (GA): the identification and characterisation of current and future scenarios for long-distance passenger multimodal transport in Europe, which will set the context for the implementation and evaluation of the MultiModX Solutions.

A scenario corresponds to a particular operational environment for multimodal transport today or in the future. A scenario is defined by a set of passenger archetypes, a regional context, relevant strategic and/or tactical policies, expected demand and supply levels, and certain disruptions. In more detail:

- Passenger archetypes are developed through a combination of machine learning, and big mobility data from agent based modelling and mobile networks. Profiling travel behaviour and decision making should allow segmenting passenger flows and modelling modal and route choice, as well as trip start times (which depend on the buffer times required by each type of passenger), which in turn drive door-to-door travel times.

- Regional archetypes are developed through a combination of machine learning and open-source data on European NUTS2 regions. The passenger archetypes, in combination with the regional context, should facilitate the modelling of urban access/egress, obviating the need to model individual passengers, whilst appropriately capturing the heterogeneity thereof.

- Relevant policies are identified, detailed and prioritised via dedicated exchanges with MultiModX's Industry Board. The effect of applying a range of strategic and tactical policies (on demand, mode choice etc.) should be analysed.

- Demand and supply data should enable creation of air and rail schedules that accommodate the demand, minimise waiting times, improve overall network connectivity through the schedule management solution (SOL400/SOL2)

- Relevant disruptions are identified and detailed via dedicated exchanges with MultiModX's Industry Board. Simulation of disruptions should enable evaluation of centralised solutions for disruption management (SOL401/SOL3).

Furthermore, these components are combined to arrive at the following scenarios to evaluate the solutions:

- Baseline intra-Spain mobility without multimodal policies, respecting air alliances.

- Intra-Spain mobility with incentivised multimodal policies (integrated ticketing and extra CO2 cost for aviation), respecting air alliances.

- Intra-Spain mobility with flight ban (180 min rail alternative) and incentivised policies, respecting air alliances.

- Baseline intra-Spain mobility without multimodal policies, allowing all connections and prioritising total passenger assignment.

- Baseline intra-Spain mobility with flight ban (180 min rail alternative) and incentivised policies, allowing all connections and prioritising total passenger assignment.
- Baseline intra-Spain mobility without multimodal policies, allowing all connections and prioritising total passenger assignment.
- Baseline intra-Spain mobility with flight ban (180 min rail alternative) and incentivised policies, allowing all connections and prioritising total passenger assignment.

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2 Introduction

2.1 Purpose of the document

This document defines the components that make up scenarios: passenger archetypes, regional context, relevant strategic and/or tactical policies, demand and supply levels, and disruptions.

By providing a detailed definition of these components and presenting the evaluation scenarios, this document aims to facilitate the successful implementation of the MultiModX solutions.

2.2 Scope

The OSED presents the operational service and environment of Scenario Definition. The overall scope of the OSED covers the definition of the operational characteristics foreseen as part of the Scenario Definition in MultiModX.

Scenario definition aims **addresses Objectives 1 of the project** as stated by the Grant Agreement (GA): the identification and characterisation of current and future scenarios for long-distance passenger multimodal transport in Europe, which will set the context for the implementation and evaluation of the MultiModX Solutions.

A scenario corresponds to a particular operational environment for multimodal transport today or in the future. A scenario is defined by a set of passenger archetypes, a regional context, relevant strategic and/or tactical policies, expected demand and supply levels, and certain disruptions. These components will be described in the document:

- Passenger archetypes are developed through a combination of machine learning, and big mobility data from agent based modelling and mobile networks. Profiling travel behaviour and decision making should allow segmenting passenger flows and modelling modal and route choice, as well as trip start times (which depend on the buffer times required by each type of passenger), which in turn drive door-to-door travel times.

- Regional archetypes are developed through a combination of machine learning and open-source data on European NUTS2 regions. The passenger archetypes, in combination with the regional context, should facilitate the modelling of urban access/egress, obviating the need to model individual passengers, whilst appropriately capturing the heterogeneity thereof.

- Relevant policies are identified, detailed and prioritised via dedicated exchanges with MultiModX's Industry Board. The effect of applying a range of strategic and tactical policies (on demand, mode choice etc.) should be analysed.

- Demand and supply data should enable creation of air and rail schedules that accommodate the demand, minimise waiting times, improve overall network connectivity through the schedule management solution (SOL400/SOL2)

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- Relevant disruptions are identified and detailed via dedicated exchanges with MultiModX's Industry Board. Simulation of disruptions should enable evaluation of centralised solutions for disruption management (SOL401/SOL3).

We will also present the scenarios which are made by combining the above components, to be used for evaluating the solutions.

2.3 Intended readership

The readers of this document would typically include a range of stakeholders involved in the rail and aviation industry, transportation planning, and policy-making. These may include SESAR JU, SESAR IR Projects, SESAR ER projects, EU-Rail, airlines, airports, rail operators, train stations, transportation planners, policymakers, urban planners, researchers and academics, consultants and advisory firms, technology developers, and environmental organizations. Obviously, an intended reader are the partners on the MultiModX project and those responsible for the development of SOL399/SOL1 , SOL400/SOL2 and of SOL401/SOL3 to ensure that the processes and usage are aligned.

2.4 Background

<u>Passenger archetypes</u>

Passenger archetypes have been previously developed in and applied in both the Modus and TRANSIT projects ([1], [2]), focusing on passenger travel characteristics such as socio-demographic profile, household size and income, travel purpose and value of travel time, frequency of travel, etc. The profiles developed in these projects are advanced upon, by applying machine-learning algorithms that process big mobility-data from mobile networks and agent-based models, to enable quantitatively described profiles that can be then used to understand demand evolution and mode-choice by archetype.

<u>Regional archetypes</u>

The Modus project defined archetypes that represent a particular airport type (e.g. hub or national airport) and the respective rail connection, either at this airport or to the nearest city [3]. The archetypes created in these projects are expanded upon, by applying machine-learning algorithms that process open-source data on NUTS2 regions of Europe, to enable distribution of origin-destination demand between regions to demand per passenger archetype. European regional archetypes are identified at NUTS 2 level, so as to map 'travel regions' types in Europe. The different European regions are classified based on the degree of applicability of multimodal solutions. This will facilitate the evaluation of the impact of multimodality at this 'travel regions' level, which could then be extrapolated to other regions of the same level even if not explicitly modelled.

<u>Policies</u>

The development of multimodal networks will be strongly influenced by recent policy developments in the air-rail context. For example, the emerging focus on inducing a shift from air to rail on routes with HSR replacement options; with currently different regional implementation status ([4], [5]). Other policies aim at the development of particular infrastructure (e.g. the Trans-European Transport

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Network, TEN-T), at updating passenger rights regulation to enhance resilience to travel disruptions, and at enabling multimodal ticketing [6]. In general, there is a lack of literature that projects the effects of such policy measures, on multimodal networks.

2.5 Structure of the document

The document starts with a description of the passenger archetypes we developed for Spain and Germany. This is followed by a description of the regional archetypes we developed for European NUTS2 regions. Next, we detail the policies and policy packages that may be used in the scenario definition. This is followed by a description of disruptions and disruption packages that may be used in the scenario definition. Finally, we describe the demand and supply schedules that may be used to define the scenarios.

2.6 Glossary of terms

Term	Definition
Air network disruption	Significant ATFM regulations applied at airports.
Disruption	Rail or air network disruptions, which are known in advance and produce a significant reduction in supply on the infrastructure of the networks.
Disruption package	Set of disruptions that are applied at the same time to the planned network.
MaaS	MaaS (Mobility as a Service) is a concept that integrates various transportation options into a single, user-friendly platform, typically accessible through a smartphone app or digital interface
OD pair	Origin and Destination pair. Refers to the start and end points of each passenger's journey. The number of O&Ds also indicates the size and complexity of a network.
Passenger archetype	A profile of passengers' travel behaviour and decision making (regarding mode choice, for instance).
Rail network disruption	Reduced throughput at nodes (rail stations) and/or links, and/or closure of links.
Regional archetype	A profile of European NUTS2 regions, created to detail the degree of applicability of internet-enabled multimodal Mobility as a Service (MaaS) concepts
Scenario	A scenario corresponds to a particular operational environment for multimodal transport today or in the future. A scenario is defined by a set of passenger archetypes, a regional context, relevant strategic and/or tactical policies, expected demand and supply levels, and certain disruptions.

Table 1: Glossary of terms

2.7 List of acronyms

Term	Definition
OSED	Operational service and environment description
SESAR	Single European sky ATM research
HSR	High speed rail

Table 2: List of acronyms

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3 Operational service and environment definition (OSED)

3.1 Scenario definition: a summary

Scenario definition addresses Objectives 1 of the project as stated by the Grant Agreement (GA): the identification and characterisation of current and future scenarios for long-distance passenger multimodal transport in Europe, which will set the context for the implementation and evaluation of the MultiModX Solutions.

A scenario corresponds to a particular operational environment for multimodal transport today or in the future. A scenario is defined by a set of passenger archetypes, a regional context, relevant strategic and/or tactical policies, expected demand and supply levels, and certain disruptions.

3.1.1 Passenger archetypes

To obtain the passenger archetypes, we utilized two distinct clustering exercises, each drawing from different datasets; one based on Spanish mobile network data, and another using data from the an agent-based model. These two approaches offer unique insights into travel behavior patterns, each with its own set of strengths and limitations.

The Spanish data clustering uses a wide range of features only related to travel behaviour (and not to sociodemographics), allowing for a nuanced characterization of long-distance trips. However, it only considers trips with at least one overnight stay, potentially missing shorter journeys. It also lacks information on trip purposes, which may limit understanding of travel motivations, particularly for business travelers.

The German clustering exercise offers a different perspective, moving focus away from purely travel behavior, and incorporating socio-demographic characteristics alongside some travel-specific variables. This approach provides insights into the relationship between personal attributes and travel patterns. However, this dataset uses fewer variables directly related to travel behaviour. On the other hand, this exercise has information on trip purpose, which provides greater understanding of travel motivations.

While both sets of archetypes are detailed below, for the first set of experiments, the Spanish archetypes will be used.

3.1.1.1 German Passenger Archetypes

For developing the German passenger archetypes, we used simulated big data from an agent-based model designed to simulate long-distance travel behaviour in Germany [reference]. The model operates at a microscopic scale, explicitly simulating individual travel choices; including mode choice, trip-purpose, trip duration, destination etc. By applying the K-means clustering algorithm on the simulated travel of the German population, we obtained the following long-distance passenger archetypes for Germany:

3.1.1.1.1 Archetype 1: The GenXer travelling mostly for business via rail

Sociodemographics

- These travellers are predominantly middle- to old-aged (large share between 25 and 65), with a mean age of 48.
- The gender distribution in this archetype is mostly female (57%).
- This archetype has the second-highest chance of being employed (55%), and the second-lowest chance of being a student (8%).
- This archetype has the highest monthly net personal income and monthly net household income among the archetypes.

Travel patterns

- Travels the shortest distances among the archetypes (259 Km on average).
- Mostly uses rail transport (64%), with the second-highest chance of using air-transport (36%).
- Trips typically last only one day.
- Travels for business purposes (49%), followed by leisure purposes (36%).
- Predominantly takes domestic trips (75%), with the second-highest chance of taking international trips (25%).

3.1.1.1.2 The GenXer travelling predominantly for private purposes via rail

Sociodemographics

- These travellers are predominantly old-aged (large share over 45 and 65), with a mean age of 56.
- The gender distribution in this archetype is equal (50% for each gender).
- This archetype has the highest chance of being employed (56%), and the lowest chance of being a student (4%).
- This archetype has the second-highest monthly net personal income, but the lowest monthly net household income, among the archetypes.

Travel patterns

- Travels the second-longest distances among the archetypes (295 Km on average).
- Predominantly uses rail transport (75%), with the lowest chance of using air-transport (25%).
- Trips typically last two or more days.
- Travels for private purposes (43%), followed by leisure purposes (30%).
- Predominantly takes domestic trips (79%), with the lowest chance of taking international trips (21%).

3.1.1.1.3 Archetype 3: The GenZ youngster going on holiday

Sociodemographics

- These travellers are predominantly very young (large share under 24), with a mean age of 26.
- The gender distribution in this archetype is mostly male (55%).

- This archetype has the highest chance of being a student (21%). The chances of being a student or being unemployed are highest at 51%.
- This archetype has the lowest monthly net personal income, and the second-highest monthly net household income, among the archetypes.

Travel patterns

- Travels the second-longest distances among the archetypes (301 Km on average).
- Mostly uses rail transport (57%), with the highest chance of using air-transport (43%).
- Trips typically last two or more days.
- Travels for leisure purposes (48%), followed by business purposes (34%).
- Mostly takes domestic trips (64%), with the highest chance of taking international trips (36%).

3.1.1.2 Spanish Passenger Archetypes

The Spanish passenger archetypes were obtained by applying the K-means clustering algorithm on mobile network data of the Spanish population. The data was provided by Orange Spain as the main data source. Clustering was conducted on the annual travel plan of each individual, extracted through a longitudinal analysis from March 2019 to February 2020 (both inclusive). This resulted in the following six archetypes:

3.1.1.2.1 Occasional weekday traveler

Sociodemographics

- These travellers are predominantly middle-aged (large share between 25 and 65).
- The gender distribution in this archetype is mostly male (53%).
- This archetype has low to medium income.

Travel patterns

- Travels the fourth-longest distances among the archetypes (372 Km on average).
- On average, takes four trips a year, mostly during the workweek
- Trips typically last two days
- Mostly uses rail transport (58%), with the second-lowest chance of using air-transport (40%).
- Predominantly takes domestic trips (96%), with the third-lowest chance of taking international trips (4%).

3.1.1.2.2 Long distance active

Sociodemographics

- These travellers are predominantly middle- to old-aged (large share between 25 and 65).
- The gender distribution in this archetype is mostly male (52%).
- This archetype has high income.

Travel patterns

- Travels the third-longest distances among the archetypes (423 Km on average).
- On average, takes ten trips a year, mostly during the holidays.
- Trips typically last five days
- Mostly uses rail transport (51%), with the fourth-highest chance of using air-transport (46%).

3.1.1.2.3 Sporadic international traveller

Sociodemographics

- These travellers are predominantly middle- to old-aged (large share between 25 and 65).
- The gender distribution in this archetype is mostly male (52%).
- This archetype has medium-to-high income.

Travel patterns

- Travels the shortest distances among the archetypes (275 Km on average).
- On average, takes three trips a year.
- Trips typically last five days
- Predominantly uses air-transport (87%), with the lowest chance of using rail (9%).
- Predominantly takes International trips (83%), with the lowest chance of taking international trips (7%).

3.1.1.2.4 International urbanite

Sociodemographics

- These travellers are predominantly middle- to old-aged (large share between 25 and 65).
- The gender distribution in this archetype is equal (50% for male and female).
- This archetype has high-to-very high income.

Travel patterns

- Travels the second-shortest distances among the archetypes (323 Km on average).
- On average, takes three trips a year, predominantly during holidays.
- Trips typically last seven days
- Predominantly uses air-transport (84%), with the second-lowest chance of using rail (11%).
- Predominantly takes International trips (81%), with the second-lowest chance of taking international trips (16%).

3.1.1.2.5 Sporadic long-haul traveller

Sociodemographics

- These travellers are predominantly middle-aged (large share between 25 and 65).
- The gender distribution in this archetype is mostly female (52%).
- This archetype has low-to-medium income.

Travel patterns

- Travels the longest distances among the archetypes (501 Km on average).
- On average, takes two trips a year.
- Trips typically last four days
- Mostly uses rail transport (52%), with the second-lowest chance of using rail (11%).
- Predominantly takes domestic trips (99%), with the lowest chance of taking international trips (1%).

3.1.1.2.6 Domestic summer traveller

Sociodemographics

- These travellers are predominantly middle- to old-aged (large share between 25 and 65).
- The gender distribution in this archetype is mostly male (51%).
- This archetype has medium-to-high income.

Travel patterns

- Travels the second-longest distances among the archetypes (467 Km on average).
- On average, takes two trips a year, predominantly during holidays.
- Trips typically last nine days
- Mostly uses rail transport (61%), with the lowest chance of using air (37%).
- Predominantly takes domestic trips (98%), with the second-lowest chance of taking international trips (2%).

3.1.2 Regional archetypes

European regional archetypes are identified at NUTS 2 level to map 'travel regions' types in Europe. The different European regions are described with a view to detail the degree of applicability of internet-enabled multimodal Mobility as a Service (MaaS) concepts. This facilitates the evaluation of the impact of multimodality at this 'travel regions' level, which could then be extrapolated to other regions of the same level even if not explicitly modelled. This creates, therefore, different sub-operational environments based on these regional archetypes.

Once the regional archetypes are identified, passenger archetypes can be associated with them, thus estimating the average compositions of passenger archetypes within a certain regional archetype. This could facilitate the creation of new experiments by distributing origin-destination demand between regions to demand per passenger archetype.

The clustering of the regions was performed considering different feature-types:

- Socio-demographics (e.g. Per capita Monthly Household Income)
- Tourist volumes (e.g. Arrivals at tourist accommodation)
- Travel behaviour (e.g. Departing air traffic)
- Innovativeness (e.g. Share of the population who ordered goods or services over the Internet)

To describe the clusters, features such as the Innovation label from the EU Regional Innovation Scoreboard, the number of airports, the railway-line density are used.

The analysis identified 3 regional archetypes within Europe which can be considered as sub-operating environments:

3.1.2.1 Archetype 1: Advanced high MaaS-potential regions

Around 24% of European regions belong to this archetype. This is the lowest share among the archetypes. Examples of regions in this cluster are Communidad de Madrid (ES30), Berlin (DE30), Il-de-France (FR10), Área Metropolitana de Lisboa (PT17).

Sociodemographics:

- Population: The average population of this cluster of regions is the highest among the archetypes.
- Population Density: The average population density of this cluster of regions is the highest among the archetypes, suggesting this is a cluster of highly developed urban regions (considering the urban/rural population density threshold of 150 persons / sq km used by the OECD).
- Age Distribution: This is a young cluster. These regions have the highest share of population aged 0-24 and close to the highest share of people aged 25-44. It also has essentially the lowest shares of population aged 45-64, and 65+.

Economic Indicators:

- Monthly per capita Disposable Income: This cluster has the highest monthly per capita disposable income among the archetypes, suggesting high purchasing power.
- E-commerce Users: This cluster has the highest share of e-commerce users, indicating advanced digital infrastructure and adoption of digital services.
- Innovation: This cluster is dominated by Innovation Leader regions (56%), followed by Strong Innovator regions (30%).

Transport infrastructure:

- Airports: This cluster has the highest number of average airports per million people among the clusters, of 2.3. The majority of these regions (57%) have between 1 to 3 airports. The airports in this cluster handle a high average number of departing passengers (23% above the average number handled by all regions in the EU).
- Railway line density: This cluster has the highest railway line density.

Travel behaviour:

- Air Traffic: This cluster has the highest per capita flights among the clusters.
- Rail Traffic: This cluster has the highest per capita rail traffic.
  - This cluster has the highest total trips per capita.
  - There is a strong preference, in fact the strongest preference among the clusters, for rail travel compared to air.

Tourism:

- This cluster has the highest number of tourist arrivals among all clusters.

MaaS Potential

This regions of this cluster represent ideal environments for MaaS adoption. These advanced urban areas benefit from exceptional infrastructure readiness with their dense railway networks and airport accessibility creating a fertile foundation for integrated mobility solutions. The predominantly young population aligns perfectly with typical early MaaS adopters, bringing digital fluency and openness to innovative mobility approaches.

The economic landscape further encourages adoption with high disposable incomes reducing price sensitivity concerns that might otherwise impede uptake. This financial comfort is complemented by widespread e-commerce usage, signalling digital readiness for app-based mobility platforms. As innovation leaders, these regions likely possess both the public sector vision and private investment capacity to support sophisticated MaaS development.

Strong use cases further drive potential adoption. High tourism creates dual markets of locals and visitors needing intuitive navigation solutions. The highest per capita trip rates across Europe indicate frequent mobility needs that would benefit from streamlined options. The demonstrated preference for rail suggests comfort with shared transportation modes that typically form MaaS backbones.

These regions can serve as innovation laboratories where comprehensive MaaS ecosystems develop first, testing subscription models, integrated payment systems, and personalized multi-modal journey planning before such features spread to less advantaged regions.

3.1.2.2 Archetype 2: Conservative regions for cautious MaaS adoption

Around 37% of European regions belong to this archetype. This is the second-highest share among the archetypes. Examples of regions in this cluster Pais Vasco (ES21), Brandenburg (DE40), Bourgogne (FR10), Lombardia (ITC4).

Sociodemographics:

- Population: The average population of this cluster of regions is close to the median for the dataset of EU regions.
- Population Density: The average population density of this cluster of regions is close to the median for EU regions. This cluster seems to have regions that are neither highly urban, nor highly rural.
- Age Distribution: These regions are old. The archetype has the highest share of people aged 65+, and of those aged 45-64. It has the lowest share of people under 25 and of those aged 25-44.

Economic Indicators:

- Monthly per capita Disposable Income: This cluster has close to the highest monthly per capita disposable income among the archetypes, suggesting high purchasing power.
- E-commerce Users: This cluster has the close to median levels of share of e-commerce users. Regions in this cluster may have digital infrastructure that is good, but not necessarily, the most advanced. The low usage of digital services may be because of the higher share of older, conservative individuals. This indicates that adoption of new internet-enabled MaaS concepts may be reasonably good, but not a mainstream phenomenon.

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- Innovation: This cluster is dominated by Moderate Innovator regions (48%) and Strong Innovator regions (36%) indicating a relatively advanced innovation ecosystem. Introduction of innovative MaaS concepts may be faster than in the third cluster, but slower than in the first cluster.

Transport infrastructure:
- Airports: This cluster has the lowest number of average airports per million people among the clusters, of 1.5. The majority of these regions (60%) have between 0 to 2 airports. The average number of departing passengers handled by the airports in this cluster is below the average number handled by all regions in the EU (by 12%).
- Railway line density: This cluster has close to the median level of railway line density for the EU, much lower than the density in the first cluster.

Travel behaviour:
- Air Traffic: This cluster has the second-highest per capita flights among the clusters.
- Rail Traffic: This cluster per capita rail traffic that is the median for EU regions.
    - This cluster has total trips per capita that is the median for EU regions.
    - There is a strong preference for rail travel compared to air, but not as high as in the case of the first cluster.

Tourism:
- This cluster has the second-highest number of tourist arrivals among all clusters.

MaaS Potential
These regions present a mixed landscape for MaaS adoption. These conservative regions with median travel activity feature infrastructure that is adequate but not exceptional - with railway density at median EU levels and fewer airports per capita than other clusters. This provides a workable foundation for MaaS implementation.

The demographic profile poses the most substantial barrier to rapid adoption. With the highest proportion of residents aged 45+ and lowest share of younger populations, these regions lack the digital-native demographics that typically drive early MaaS uptake. This age distribution aligns with the moderate e-commerce usage, suggesting some digital hesitancy that could slow MaaS adoption. Economic factors are more favourable, with near-top disposable income levels indicating purchasing power that could overcome price sensitivity concerns. However, this advantage may be partially offset by more conservative spending patterns typical of older populations.

As predominantly Moderate to Strong Innovator regions, these areas have innovation ecosystems capable of supporting MaaS development, though likely at a more measured pace than Cluster one. The median level of total trips per capita and preference for rail (though less pronounced than in Cluster 1) indicate reasonable demand for integrated mobility solutions.
The significant tourist arrivals represent perhaps the strongest catalyst for MaaS adoption, as visitors typically seek simple navigation solutions regardless of local residents' preferences. This tourism factor might drive initial MaaS implementations focused on visitor experiences that could gradually expand to serve residents.

MaaS adoption in these regions will likely follow a phased pattern, beginning with tourism-oriented solutions and gradually expanding as older residents become more comfortable with digital mobility platforms.

3.1.2.3 Archetype 3: Emerging low MaaS-potential regions

Around 40% of European regions belong to this archetype. This is the highest share among the archetypes. Examples of regions in this cluster Communitat Valenciana (ES52), Prov. Luxembourg (BE34), Haute-Normande (FRD2), Mellersta Norrland (SE32).

Sociodemographics:

- Population: The average population of this cluster of regions is the lowest among the clusters.
- Population Density: The average population density of this cluster of regions is the lowest among the clusters; indicating these are likely rural or peripheral regions.
- Age Distribution: This cluster has a high share of population aged 0-24 and the highest share of people aged 25-44, suggesting this is a young cluster. It has essentially the lowest shares of population aged 45-64, and 65+.

Economic Indicators:

- Monthly per capita Disposable Income: This cluster has the lowest monthly per capita disposable income among the clusters, indicating lower purchasing power.
- E-commerce Users: This cluster has the median share of e-commerce users, in spite of the majority of the population being young. Regions in this cluster may have digital infrastructure that is good, but not necessarily, the most advanced. This indicates that introduction of new internet-enabled MaaS concepts may be slow.
- Innovation: This cluster is dominated by Emerging Innovators (58%), followed by Moderate Innovators (23%). This suggests a developing innovation ecosystem, and introduction of innovative MaaS concepts may be slower than in the other two clusters.

Transport infrastructure:

- Airports: Along with the first cluster, this one has the highest number of average airports per million people among the clusters, of 2.3. The majority of these regions (74%) have between 0 to 2 airports. The average number of departing passengers handled by the airports in this cluster is slightly below the average number handled by all regions in the EU (by 9%).
- Railway line density: This cluster has lowest railway line density among the clusters, somewhat lower than the second cluster, and much lower than the density in the first cluster.

Travel behaviour:

- Air Traffic: This cluster has the lowest levels of air traffic per capita.
- Rail Traffic: This cluster has the lowest levels of rail traffic per capita.
  - This cluster has the lowest total trips per capita.
  - While there is a stronger preference for rail travel, this cluster has the highest preference for air travel among the clusters.

Tourism:

- This cluster has the lowest number of tourist arrivals among all clusters.

MaaS Potential

These regions face significant barriers to MaaS adoption despite some demographic advantages. These sparsely populated rural areas contend with fundamental infrastructure limitations that undermine MaaS viability. The lowest railway line density create a fragmented mobility landscape that's difficult to integrate into cohesive MaaS platforms. While these regions have relatively high airports per capita, the actual passenger volumes and overall trip rates are the lowest among all clusters, indicating minimal travel activity that reduces the practical value of comprehensive mobility services.

The younger population profile initially appears favorable for digital adoption, with high proportions of residents aged 0-44. However, this demographic advantage is offset by only median e-commerce usage, suggesting digital infrastructure limitations rather than age-related hesitancy. The predominance of Emerging Innovator status (58%) indicates nascent innovation ecosystems that may lack the technical expertise and investment capacity to develop sophisticated MaaS solutions.

Economic constraints present perhaps the most substantial barrier, with the lowest disposable income among all clusters creating high price sensitivity. This economic reality makes premium MaaS subscription models particularly challenging to implement. The low tourism rates further remove a potential adoption catalyst that might otherwise drive initial implementation.

The preference for air travel over rail (highest among clusters) suggests a transportation landscape defined by necessity rather than choice - with residents likely traveling long distances occasionally rather than making frequent shorter trips that would benefit from integrated mobility platforms.

MaaS implementation in these regions will likely be limited to targeted solutions addressing specific pain points rather than comprehensive platforms, with successful adoption requiring significant customization to rural mobility patterns and substantial public subsidies to overcome economic barriers.

3.1.3 Policies

For our experiments, different combinations of polices (i.e., policy packs) may be considered. The policies were identified, detailed and prioritised (by relevancy scores) via dedicated exchanges with MultiModX's Industry Board. Identified policies are listed in Table 3.

Policy	Policy instruments/Parameters to vary	Relevancy (max value of 5.0)
Short-haul flight ban	1. Type of policy:	3.8

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	• Time-based: duration of flight to ban (2h / 3h) • Distance-based: length of flight to ban (300km / 500km) 2. Operations impacted: all / non-connecting / non-hub connections	
Tax changes	1. Location 2. Magnitude: frequent flyer levy, incentivizing rail, CO2 cost	3.4
Integrated ticketing	1. Level of integration 2. Business oriented policies • Alliances between airlines and rail operators • Rebooking approaches	4.1
Passengers' duty of care and compensation policies	1. Arrival delay threshold for compensation (3/5/9/12 hours) 2. Rule for sharing liability: share of journey-duration or share of ticket- cost 4. Exclusion rules (e.g. ATFM delay excluded)	3.4
Passenger disruption management	1. Type of compensation: as-soon-as-possible re-routing, or reimbursements	4.5
Various mechanisms to manage multimodality on a day-to-day basis		3.7

Table 3: Policies that inform the simulated policy packages.

Some policy packages under consideration are:

Reference (no particular policies)

- No short haul flight ban
- No tax changes
- No integrated ticketing
  - No alliances between rail operators and all
  - No rebooking for multimodal tickets
- No passenger duty of care (part of post-processing)
- No day-to-day multimodality management

Multimodality incentivised

- No short haul flight ban
- Tax changes: CO2 tax (in €/kg)
- Integrated ticketing
  - Fully integrated ticketing
  - All rail operators ally with all airlines
  - Rebooking via ticket operator
- No passenger duty of care (part of post-processing)
- No day-to-day multimodality management

Multimodality enforced

- Short haul flight ban for flights with a duration of up to 2h 30
- Tax changes: CO2 tax (in €/kg)
- Integrated ticketing
    - Fully integrated ticketing
    - All rail operators ally with all airlinedemas
    - Rebooking via ticket operator
- No passenger duty of care (part of post-processing)
- No day-to-day multimodality management

3.1.4 Disruptions

For our experiments, different combinations of disruptions (i.e., disruption packs) may be considered. The disruptions were identified, detailed and prioritised (by relevancy scores) via dedicated exchanges with MultiModX's Industry Board. Identified disruptions are listed in Table 4.

Disruption	Impacted Network	Parameters to vary	Relevancy (max value of 10.0)
Rail corridor closed due to technical failure, accidents	Rail	1. Which corridor(s)	4
Rail corridor capacity reduction due to technical failure, accidents, rolling stock breakdowns	Rail	1. Which corridor(s) 2. Which throughput	11
Airport closure due to adverse weather, storm/flood, strikes	Air	1. Which airports 2. Time of occurrence	3
Airport capacity reduction due to strikes, technical failures, adverse weather	Air	1. Which airports 2. New capacity	7
Reduced airspace capacity due to controller shortages, technical failures	Air	1. Which airspace OD pairs are impacted 2. Distribution of delays	5
Airspace closure due to adverse weather, technical failures, controller shortages etc.		1. Which airspace OD pairs are impacted	5
Multiple simultaneous closures/capacity reductions in the network			7

Table 4: Disruptions that inform the simulated disruption packages.

Some disruption packs being considered are:

Reference (no disruptions)

- Neither air nor rail networks disrupted

Air network disrupted

- Significant disruption in airport capacities
- Based on historical ATFM regulations at hub airport(s), which generated high delays (one representative per Case Study)

Rail network disrupted

- Significant disruption in rail links capacities
- Based on the most important links

Air & Rail network disrupted

- Significant disruption in both rail and air networks

3.1.5 Supply and Demand

Flight schedules for 2019, specifically for September 14, 2019, are obtained from OAG data. Rail timetables are obtained from UIC rail timetables from 2023. These schedules are applied across regions (Germany, Spain, Germany-Spain). Demand data is obtained via various sources. The sources for Demand and Schedules are detailed below in table 5.

Data/Region	Germany	Spain	Germany-Spain
Supply (flight schedules / rail timetables)	Flight schedules: OAG 2019 data for September 14, 2019 Rail timetables: UIC rail timetables 2023	Flight schedules: OAG 2019 data for September 14, 2019 Rail timetables: UIC rail timetables 2023	Flight schedules: OAG 2019 data for September 14, 2019 Rail timetables: UIC rail timetables 2023
Demand (on OD pair basis)	Demand on a NUTS regions level from Aviation Weekly and from SABRE	Demand on a NUTS regions level from Aviation Weekly Mobile network based travel pattern data	Demand on a NUTS regions level from Aviation Weekly and from SABRE

Table 5: Data sources for demand and supply.

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3.1.6 Reference scenarios for evaluation

By combining the above described components in different ways, we get the scenarios detailed in table 6.

Scenario number	Description
cs10.pp00.nd00.so00.00	Baseline intra-Spain mobility without multimodal policies, respecting air alliances.
cs10.pp10.nd00.so00.00	Intra-Spain mobility with incentivised multimodal policies (integrated ticketing and extra CO_2 cost for aviation), respecting air alliances.
cs10.pp20.nd00.so00.00	Intra-Spain mobility with flight ban (180 min rail alternative) and incentivised policies, respecting air alliances.
cs10.pp00.nd02.so00.00	Baseline intra-Spain mobility without multimodal policies, allowing all connections and prioritising total passenger assignment.
cs10.pp20.nd02.so00.00	Baseline intra-Spain mobility with flight ban (180 min rail alternative) and incentivised policies, allowing all connections and prioritising total passenger assignment.
cs10.pp00.nd02.so10.02	Baseline intra-Spain mobility without multimodal policies, allowing all connections and prioritising total passenger assignment.
cs10.pp20.nd02.so10.01	Baseline intra-Spain mobility with flight ban (180 min rail alternative) and incentivised policies, allowing all connections and prioritising total passenger assignment.

Table 6: Reference scenarios for evaluating the solutions.

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4 References

4.1 Applicable documents

This OSED complies with the requirements set out in the following documents:

Content integration

[1] …

Content development

[2] …

System and service development

[3] …

Performance management

[4] …

Validation

[5] …

System engineering

[6] …

Safety

[7] …

Human performance

[8] …

Environment assessment

[9] …

Security

[10] …

Project and programme management

[11]101114815 MultiModX Grant Agreement, 31/05/2023

[12]SESAR 3 JU Project Handbook – Programme Execution Framework, 13/01/2023, 1.0

4.2 Reference documents

[1] Paul, A., Valput, D., Hernández, P., Cook, A. J., Arich, P., & Kadour, H. (2021). Modus D4. 1 Interface to modal choice model. SESAR.

[2] TRANSIT Consortium (2021b). D4.1 Methodologies and Mobility Analytics Algorithms for the Analysis of the Door-to-Door Passenger Journey

[3] Modus consortium (2021a). D4.1 Interface to modal choice model.

[4] Ministère de la transition écologique (2021). Projet de loi Climat & Résilience - "Se déplacer" : Ça change quoi dans nos vies?, http://www.ecologie.gouv.fr/projet-loi-climat-resilience-deputes-viennent-finir-lexamen-des-articles-du-titre-iii-se-deplacer-ca

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[6] European Commission (2020). Sustainable and smart mobility strategy: Putting european transport on track for the future," 2020. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0789&from=EN