Concept of Operations for ATM integration in intermodal transport system [Concept Outline]

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X-TEAM D2D

EXTENDED ATM FOR DOOR2DOOR TRAVEL

This Project Management Plan is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 891061 under European Union's Horizon 2020 research and innovation programme.

Abstract

X-TEAM D2D project aims at defining, developing and initially validating a Concept of Operations (ConOps) for the seamless integration of ATM and Air Transport into an overall intermodal network, including other available transportation means (surface, water), to contribute to the ACARE SRIA FlightPath 2050 goal. X-TEAM D2D project aims contributing to this goal by providing and preliminarily validating a ConOps for seamless door-to-door mobility in urban and suburban (up to regional) environment, i.e. X-TEAM D2D target scenario addresses the connection of a big metropolis with the surrounding area (up to country-wide level).

The project is focused on the consideration of ConOps for ATM integration in intermodal transport network serving Urban and Extended Urban mobility, considering the transportation and passengers service scenarios envisaged for the next decades, according to baseline (2025), intermediate (2035) and final (2050) time horizons.

The target ConOps will encompass both the transportation platforms integration concepts and the innovative seamless mobility as a service including ATM concepts. The ConOps will be preliminarily evaluated against already existing and specifically defined applicable KPAs and KPIs, implementing both qualitative and quantitative performances assessment approach.

The X-TEAM D2D project will develop a simulation-based platform for validating the proposed concept, considering the most relevant elements of the transport in the future such as interfaces mode-mode, high-level network model, passenger-centric paradigm.

In particular, the project WP3 activities address the Definition of a Concept of Operations (ConOps) supporting the seamless integration of ATM into an overall intermodal network from the perspective of the transport systems and infrastructures, whereas the WP4 addresses the integration aspects from the service point of view.

This deliverable D3.1, therefore, reports the outcomes of the WP3 activities up to the current stage and in particular it provides the initial definition (i.e. the Concept Outline) of the Concept of Operations for ATM integration in intermodal transport system. This deliverable will be then updated based on the evolution of the project activities, to reach its final form (i.e. the Concept Description) in the version D3.2, expected to be issued on M22 (i.e. by March 2022).

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The project has been funded under Grant Agreement No 891061.

This deliverable reports the outcomes of the studies carried out in the Task 3.1 "Technological enablers", whose activities have been concluded, and in the Task 3.2 "Extended ATM Concept of Operations for transports integration", whose activities have been concluded with reference to their first phase and will continue with the subsequent refinement phase that will lead to D3.2 "Concept of Operations for ATM integration in intermodal transport system [Concept Description]". Activities of the Task 3.3 "Change management" are not yet expected to be started, according to the planned schedule, therefore they are out of the scope of this document and will be reported in D3.2, as expected.

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[1] The opinions expressed herein reflect the author's view only. Under no circumstances shall the SESAR Joint Undertaking be responsible for any use that may be made of the information contained herein.

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1.2 Acronyms

4G	Fourth Generation
5G	Fifth Generation
A-CDM	Airport Collaborative Decision Making
ADS-B	Automatic Dependent Surveillance – Broadcast
ADSP	ATM Data Service Providers
AI	Artificial Intelligence
AIS	Automatic Identification System
ANSP	Air Navigation Service Provider
ATM	Air Traffic Management
BT	Business Traveller
C2	Command and Control
CAT	Clear Air Turbulence
CCAM	Connected, Cooperative and Automated Mobility
CNS	Communication, Navigation and Surveillance
ConOps	Concept of Operations
D2D	Door-to-Door
EHPS	Electric and/or Hybrid Propulsion System
EU	European Union

FAA	Federal Aviation Administration
GIS	Geographic Information System
ICT	Information and Communication Technologies
IMC	Instrumental Meteorological Conditions
IoT	Internet of Things
IT	Information Technology
KPA	Key Performance Area
KPI	Key Performance Indicator
LEO	Low Earth Orbit
LTE	Long Term Evolution
MaaS	Mobility as a Service
MM	Multimodal Mobility
NFZ	No-Fly Zone
NMS	Network Management System
NMS	New Mobility Services
PATS	Personal Air Transport System
PEV	Personal Electric Vehicle
SATS	Small Air Transport System
SESAR	Single European Sky ATM Research
SJU	SESAR Joint Undertaking
STOL	Short Take Off and Landing
TBO	Trajectory Based Operations
TEN-T	Trans European Transport Network
UAM	Urban Air Mobility
UAS	Unmanned Aerial System
UTM	Unmanned Traffic Management
V2G	Vehicle-to-Grid
V2I	Vehicle-to-Infrastructure

V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VFT	Visiting Friends and relatives Traveller
VLL	Very Low Level
VTOL	Vertical Take Off and Landing
X-TEAM D2D	eXTEnded AtM for Door2Door travel
WP	Work Package

2 Project Objectives

High level aim of the X-TEAM D2D project is to define, develop and initially validate a Concept of Operations (ConOps) supporting the seamless integration of Air Traffic Management (ATM) and Air Transport into an overall intermodal network, including other available transportation means (surface, water), to contribute enabling the door-to-door connectivity, in up to 4 hours, between any location in Europe, in compliance with the target assigned by the ACARE SRIA FlightPath 2050 goals.

In particular, the X-TEAM D2D project is focused on the detailed consideration of ConOps for ATM integration in intermodal transport network serving Urban and Extended Urban (up to Regional) mobility, considering the transportation and passengers service scenarios envisaged for the next decades, according to baseline (2025), intermediate (2035) and final (2050) time horizons.

The target ConOps provided and initially validated by the X-TEAM D2D project encompasses both the transportation platforms integration concepts and the innovative seamless mobility as a service including ATM concepts. The developed ConOps, then, will be also preliminarily evaluated against already existing and specifically defined applicable Key Performance Areas (KPA) and Key Performance Indicators (KPI), implementing both qualitative and, where possible, also quantitative performances assessment approach.

In the project activities, the integration of ATM and air transport into overall intermodal transport system is considered not only with respect to currently available transportation alternatives on the surface and water but also with respect to emerging new mobility forms that are envisaged for the next decades. In particular, emerging innovative mobility paradigms are considered, including: extended urban and regional air transport (Small Air Transport (SAT), Personal Air Transport System (PATS), vertical urban mobility (Urban Air Mobility (UAM)), road autonomous mobility (autonomous cars and buses), high-speed rail mobility (including Hyper-Loop related concepts), water autonomous mobility (autonomous vessels). In addition, emerging disruptive concepts aimed to implement seamless mobility of passengers by using passengers' pods (e.g. "*Link and Fly*" concept proposed by AKKA Technologies [2] and "*Clip-Air*" concept proposed by Switzerland's Federal Polytechnic Institute [3]) are considered from the perspective of ATM integration into intermodal transport. The X-TEAM D2D project, therefore, analyses and reviews both the status quo of different existing transport modes in Europe and the new emerging ones that new technology is being developed for, all of them immerse in the on-demand and shared economy which in combination with passenger-centric view will revolutionize the future transport modes.

While pursuing the above aim, the project considers the outcomes of other EU funded projects aimed to support the intermodal transport (e.g. BigData4ATM [4], DORA [5]) and addressing not only air transport but also other transport means on ground and water (e.g. applicable projects addressing the impact of a new airport to the ground transportation in a certain area) and also considers available studies in literature.

Under the above outlined overall objectives of X-TEAM D2D, one specific aim is to develop a simulation-based platform for validating the concept proposed in the project. This platform will consider the most relevant elements of the transport in the future such as interfaces mode-mode, high-level network model, passenger-centric paradigm. The X-TEAM D2D proposed ConOps, therefore, will be validated with the simulation platform and a description of the semantic values of future KPIs and a diagnosis of the inefficiencies of the ConOps will be provided.

In order to better specify the scope of the X-TEAM D2D project in the wider framework of the FlightPath 2050 global target, it is here specified that X-TEAM D2D does not address the complete FlightPath target of door-to-door travel between any location in Europe in up to 4 hours but the project aims at contributing to this goal by providing and preliminarily validating a ConOps for seamless door-to-door mobility in urban and suburban (up to regional) environment: X-TEAM D2D target scenario addresses the connection of a big metropolis with the surrounding area (up to country-wide level).

3 Background framework and assumptions

3.1 Assumptions and definitions

In this section, the main assumptions and definitions both on the level of project as well as considered area will be provided.

It is worth noticing here that considerations of regulatory framework for service provision are out of the scope of this document, because addressed in the project WP4. Therefore, only the applicable outcomes from the D2.1 "Future Scenarios and barriers" document [6] will be considered here, while more specific development of regulatory aspects will be addressed in WP4.

The main assumptions used in this study are indicated and described in the following.

Three time horizons: The Concept of Operation (ConOps) will be defined according to an incremental approach that encompasses three time horizons: the initial (2025), the intermediate (2035) and the final target (2050) time horizons. The scenarios definition according to such approach has been addressed in the project deliverable D2.1 "Future Scenarios and barriers" [6]. The full deployment of the X-TEAM D2D proposed final Concept of Operation, therefore, is expected from 2050 and the evolution towards this final stage is described according to baseline (2025) and intermediate (2035) ConOps steps.

Passenger transport, passenger centredness: The developed ConOps covers exclusively passenger transport on urban, suburban up to regional level including connections to/from the both regional and hub airports.

The integrated urban/suburban transport network is determined and specified by set of drivers, trends and factors of various nature identified within the scope of WP2 and described in form of scenarios in D2.1 "Future Scenarios and barriers" [6].

Final (2050) scenario description with regard to (according incremental approach):

Global perspective/Economy:

- Chinese economy to overtake USA with India taking 3rd place. Asia accounting for about 50% of global GDP. International institutions will have to adapt to allow China and India to exert greater influence and let the world become multipolar.
- Over 80% of European citizens live in urban areas. The number of economically active people to the number of children and the elderly will decrease due to ageing of the population.
- A mass rise of the middle class which together with the upper class should exceed 80% of population.
- Digitalisation and mobile communications will grant universal access to various services. The fourth industrial revolution will lead to decline in living costs, value-driven consumption and demographic shift to regional cities or metropoles.

European policy/mobility:

- Net-zero emissions in transport.
- The Comprehensive TEN-T Network completed.
- Walkable cities, domination of soft modes, mass transit, NMS, CCAM, UAM.
- Digitalisation in transport together with algorithmic governance will enable automation in almost all modes of transport and allow for management from complex-metropolitan, multimodal transport system level leading to significant progress in operational efficiency.

Regulatory:

- The delivery of the Digital European Sky should be completed enabling efficient optimisation and management including unexpected disruptions.
- Certification standards enabling introduction into operation of unmanned passenger transport over populated areas are available. Covering airworthiness of new aircraft configurations (e.g. VTOLs) as well as required infrastructure like intra urban vertiports/vertistops.

Airframe technologies:

- Numerous new technologies enabling new air mobility (PATS, SATS, STOL, VTOL) will achieve maturity allowing for introduction into the market of new types of electric/zero emission air (also roadable) vehicles able to operate to and from densely populated urban areas.

Surface transport technologies:

- Electrification of surface urban mobility significantly progressed disabling fossil fuel powered traffic in urban areas.
- Main traffic routes will be dominated by autonomous transport (buses, cars, trains, etc. managed from the level of system of systems) making the traffic more flexible, passenger needs oriented, efficient, predictable and smooth.

Use cases/passenger perspective:

- Inclusive design as one of main features of future transport system reflecting the needs of aging population.
- Dynamic timetables and routing of mass transport means enabled by automation, digitalisation and ability to near-real time demand forecasting driven by access to privately generated data.

Barriers: Implementation of all assumptions and turning defined use cases into real situations in future require overcoming of numerous barriers of various nature. Four groups of barriers were identified:

- policy and strategy planning,
- digitalisation,

- hardware technology availability,
- unconstrained data collecting, processing and sharing.

3.2 Overall approach

In general, each ConOps should be structured by carefully considering eventual risks, performance estimates, temporal developments and validation processes. Below, the approaches that this ConOps follows as guidelines are reported:

Risk based

The ConOps, in line with the EASA regulation [7], follows a risk-based approach. Broadly, this means that the level of "effort" devoted to maintaining safety is proportional to the risk associated with not doing so.

Performance based

The ConOps adopts a performance-based approach, being evaluated against already existing and specifically defined applicable Key Performance Areas (**KPAs**) and Key Performance Indicators (**KPIs**), implementing both qualitative and, where possible, also quantitative performances assessment approach [8].

Stepwise approach

The ConOps follows a stepwise approach, considering the transportation and passengers service scenarios envisaged for the next decades, according to baseline (2025), intermediate (2035) and final (2050) time horizons.

Validation based

Since X-TEAM D2D is an exploratory research project, the various concept elements should be validated before deployment. Therefore, the ConOps will be validated with a specific simulation platform. In addition, a description of the semantic values of future KPIs and a diagnosis of the inefficiencies will be provided.

3.3 Study logic

The ConOps will have to respond to user needs and be consistent with the evolution of the global economy. Mobility is at the heart of the project and the concepts proposed must be attractive in terms of sustainability and advantages offered.

Here, the term "sustainability" is intended as an integrated factor between environmental, economic and social elements, i.e. green approach, accessible costs for users and greater well-being for all.

In addition, the main advantage offered by the ConOps proposed will be the passenger-centric approach that puts passenger needs and desires at the centre of future solutions, introducing the fundamental concept of "passenger trajectory".

Therefore, to achieve these goals, the ConOps will be based on the following implications:

- Intermodal transport network → Passenger trajectory
- Integrated infrastructure → Accessible costs
- Personalized services → User attractive
- Electrification → Green approach

The logic diagram shown in Figure 1 schematises the work carried out by the X-TEAM D2D Consortium for the preparation of the initial ConOps (concept outline) addressed in the project WP3 and WP4 activities:

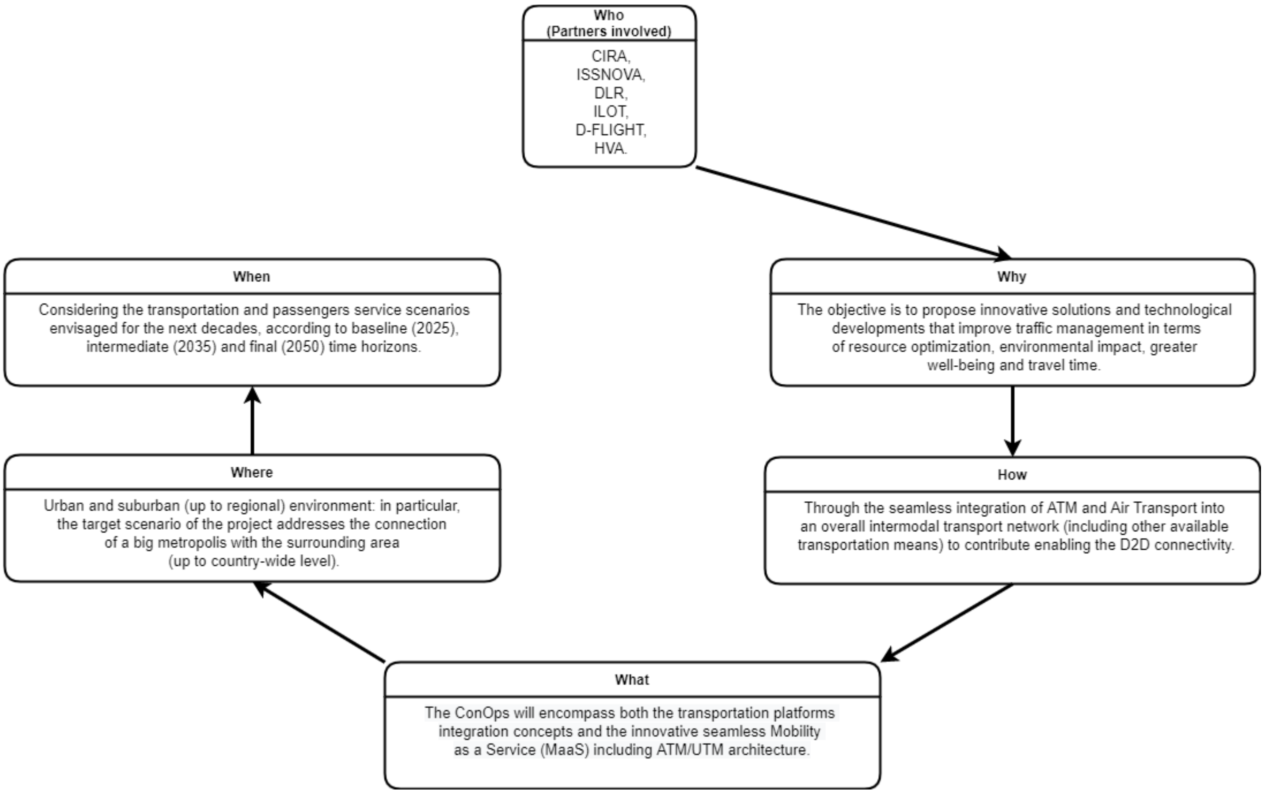

Figure 1 – ConOps preparation activities logic diagram

In terms of the ConOps contents definition and studies execution, then, they have been implemented according to the approach reported in the following Figure 2:

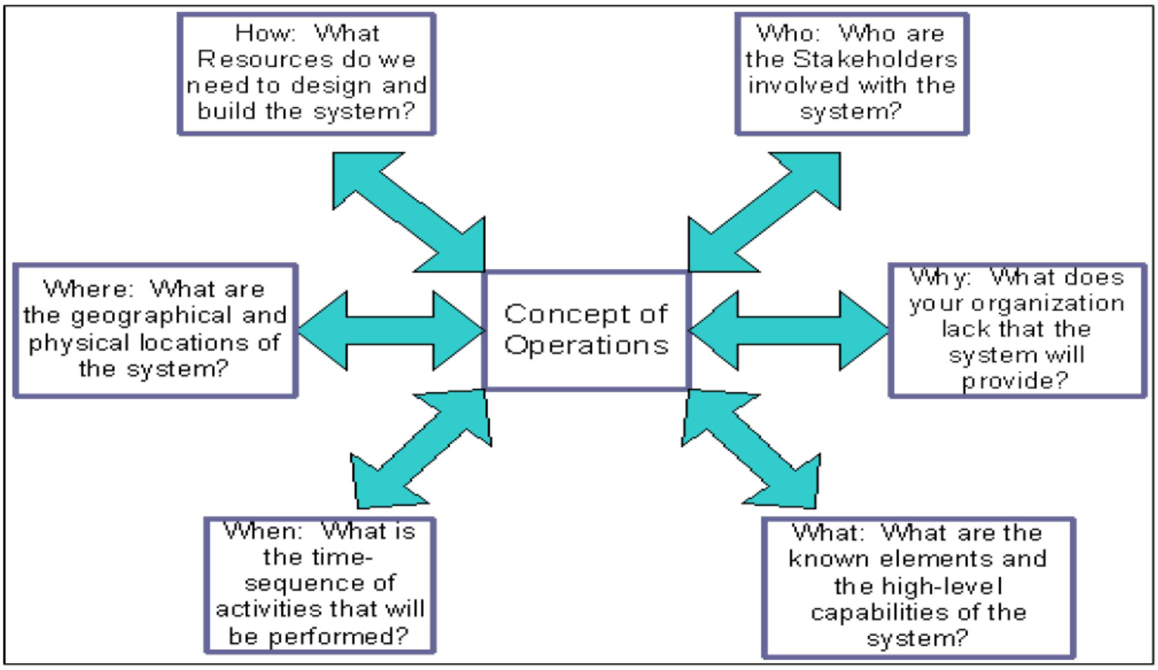

Figure 2 – ConOps contents definition study logic

4 Operational context description

The rapid development of aerospace technology observed during last decade, especially in the area of electrical propulsion, creates unprecedented opportunity for small aviation transport revitalisation. New aircraft concepts and configurations taking advantage from solutions like mentioned electric propulsion, distributed propulsion, convertible airframe and supported by progressing digitalisation and automation allow for considering a small aircraft as integrated part of future green and sustainable urban and suburban passenger transport system, commonly known as Urban Air Mobility (UAM).

One of key success factors for such defined air transportation is service affordability, which in aviation almost always is fundamental. Here it can be achieved through maximisation of efficiency on all operational levels. It can be possible only if UAM is considered as part of fully integrated urban and suburban transport system. Deep and multi-aspect integration is the only way to make UAM contributing or even enabling the four hours from door to door goal defined in FlightPath 2050.

Transport integration is an organizational process through which the planning and delivery of elements of transport system are brought together across modes, sectors, operators and institutions with the aim of increasing the net environmental and societal benefits [9]. The process of integration should cover three dimensions:

- Physical interface between the modes covering the convenient, time and effort efficient change/transfer nodes related mainly to infrastructure planning.
- Operational integration between modes, understood as coordination between transport modes to be achieved through management and digital integration, starting with data exchange and common fleet, resource, emergency, safety, risk and infrastructure management and ending with a metropolitan-wide traffic management system.
- Service integration from passenger perspective, i.e. common fare, common and paperless ticketing system, etc.

The overall X-TEAM D2D ConOps is designed in the framework of the WP3 and WP4 activities and is addressed by the deliverables D3.1 (this document) and D4.1 [10], which will evolve towards their final maturity in their final versions D3.2 and D4.2, according to future planned project activities. Physical and service integration dimensions are addressed as part of the overall Concept of Operation for urban and suburban integrated transport system in this document, whereas the operational integration will be part of operational ConOps D4.1.

5 Objectives of the intermodal transport system and service blueprint

5.1 Objectives of the intermodal transport system including ATM and UTM

In compliance with the target assigned by the ACARE SRIA FlightPath 2050 goals, the objective of the X-TEAM D2D project is to contribute enabling the door-to-door connectivity, between any location in Europe, in up to four hours. The project proposed solution to such challenging target is the integration of ATM and air transport into overall Intermodal transport system, taking into consideration not only the currently available transportation alternatives on the surface and water but also the emerging new mobility forms that are envisaged for the next decades.

Moreover, the project analyses both the *status quo* of different transport modes available in Europe and the emerging ones that new technology is being developed for, all of them immersing in the on-demand and shared economy, which will revolutionize future transport modes in combination with the passenger-centric view.

The ConOps will be validated with the suitably developed simulation platform and evaluated against already existing and specifically defined applicable KPAs and KPIs, implementing both qualitative and quantitative performance assessment approaches.

This document focuses in particular on the study of a concept of operations (preliminary, to be refined in the prosecution of the project activities) for the integration of ATM and Air Transport into an overall intermodal transport network (including other available transportation means) for seamless door-to-door mobility in the urban and suburban environment, considering passengers service scenarios envisaged for the next decades, according to baseline (2025), intermediate (2035) and final (2050) time horizons.

Based on the analysis of Use Cases and Scenario definition provided by the project deliverable document D2.1 “Future Reference Scenarios and barriers” [6], it is possible to identify the common user requirements that are applicable to the intermodal system.

The analysis of the passenger profile, previously carried out in the D2.1, distinguished the types of users into two macro families [6]:

- the **business traveller**, who moves for work reasons;
- and **other travellers**, for which a category called "Visiting friends and relatives traveller" has been defined, which includes travellers for holidays or for family reasons.

For the two types of users, their profiles were defined, analysing their characteristics and needs, and a study was carried out on possible behaviours [6]. All this was obviously differentiated for the three-time scenarios under examination (2025, 2035 and 2050), as the user's needs change with the times, in particular with the specific opportunities and technologies of each era.

After this, a study of the use cases was carried out considering the two types of users in the three points in time (2025, 2035 and 2050). Moreover, three types of external disturbances that could afflict the system are considered for each scenario, and how the user and the system respond to this stimulus, which has led to the drafting of **18 different use cases**.

Under a passenger centred perspective, the multimodal mobility service should be designed in order to take into account the key information about the passengers expected needs that could define the actions constituting the door-to-door (D2D) travel to be performed by a given passenger in such time horizon.

Therefore, the passenger key goals and behaviours concur to the design of the services that the system must provide at the various stages of the multimodal journey, also providing indications on the alternative services in the event of a travel disruption. The following tables provide an overview of the passenger high level goals and behaviours for each passenger profile, distinguished by time horizon. A detailed analysis of passengers'characteristics and corresponding requirements is provided in the project deliverable D4.1 [10].

Table 1 – Passenger high level goals and behaviours: 2025 scenario

Passenger Type	High level goals and behaviours
Business Traveller (**BT**)	❖ The users intend to reach the meeting place and to work on time. ❖ They intend to stay the time strictly necessary. ❖ They prefer the possibility of returning within the day. ❖ They accept plan changes as long as they allow to reach the target location on time, regardless of the means of transport used.
Visiting friends and relatives traveller: (**VFT**)	❖ The users intend to join family, friends or relatives on occasions of family reunions or events. ❖ They accept plan changes as long as they allow to reach the target his location on time, regardless of the means of transport used. ❖ Generally, they prefer the combination with the lowest possible cost, even if this involves a longer duration of the trip.

Table 2 – Passenger high level goals and behaviours: 2035 scenario

Passenger Type	High level goals and behaviours
Business Traveller (**BT**)	❖ The users intend to reach the meeting place and to work on time. ❖ They prefer to travel comfortably. ❖ They prefer types of transport that allow to work while traveling.
Visiting friends and relatives traveller: (**VFT**)	❖ The users intend to join family, friends or relatives on occasions of family reunions or events. ❖ They do not accept all types of transport offered, as they could travel in the company of children and/or even bulky luggage.

Table 3 – Passenger high level goals and behaviours: 2050 scenario

Passenger Type	High level goals and behaviours
Business Traveller (**BT**)	❖ The users intend to reach the meeting place and to work on time. ❖ They prefer environmentally sustainable means of transport. ❖ They may be interested in extra support services.
Visiting friends and relatives traveller: (**VFT**)	❖ The users intend to join family, friends or relatives on occasions of family reunions or events. ❖ They are interested in cheap means of transport. ❖ They do not require extra support services.

5.2 Intermodal transport service blueprint

5.2.1 Overview

Service blueprinting is a method for designing, assessing, and improving services. The technique of service blueprinting was developed through the tradition of service design ([11]-[12]) and has also found applications in diagnosing problems related to operational efficiency. As a method of service design, blueprinting is concerned with user-centeredness and the broader service ecosystem [13]. Service blueprinting is particularly effective at illuminating the complexities of new services, such as multimodal mobility services, which are often accompanied by new sets of challenges and opportunities for both end users (in X-TEAM D2D the passengers) and service providers (that include, in the X-TEAM D2D view, the operators of each travel leg, the provider of any infrastructure such as the ATC service, the Network Manager and any data exchange service provider). In X-TEAM D2D, the service blueprinting is used to facilitate the clarification of roles and interactions among the stakeholders, supporting the Use Cases definition: the graphical representation of multimodal seamless journey according to the X-TEAM D2D perspective will allow to go in depth in the organizational and cooperative aspects of the seamless journey, orchestrating the whole of tangible and intangible assets that are needed to match the variety of passengers needs at the several step of the D2D travel.

A service blueprint is a diagram that displays the entire process of service delivery, by listing all the activities that happen at each stage, performed by the different roles involved. To complete this blueprint, the workflow of a service is visually represented through time according to the service components of the blueprint. The blueprint then shows the different parts of a service at various stages, revealing holistically the relationships among various spaces, staff, and technologies that comprise the service so that the blueprint represents a conceptual model of a service as it appears to the service providers.

Usually, the service blueprint is built by first listing all the actors involved in the service process on a vertical axis, and all the steps required to deliver the service on the horizontal axis. The resulting matrix allows to represent the flow of actions that each role needs to perform along the process, highlighting the actions that the user can see (above the line of visibility) and the ones that happen in the back-office (below the line of visibility). Roles can be performed by human beings or other types of entities (organizations, departments, artificial intelligences, machines, etc.) [14].

5.2.2 Methodology

For the service blueprinting of X-TEAM D2D multimodal mobility service, the following elements are depicted:

- journey phase (macro steps of the journey, from planning to single leg, to post travel management);
- setting (physical site where the passenger is when executes the action);
- passenger actions (steps of the use case);
- tangible evidence (mean enabling action's execution by the passenger);
- "line of interaction" (delineates the part of the mobility service experienced by the passengers/that create passengers' experience);
- data provided to passenger;
- onstage employee actions (front-line staff interacting with the passenger);
- "line of visibility" (delineates the service components that are visible to the passenger);
- backstage employee actions (staff not directly involved in passenger interactions);
- support systems (technical infrastructure beyond the tangible evidence to passenger).

The following Figure 3 provides the template for the X-TEAM D2D service blueprinting (there will be a possible review with reference to the Use Cases described in the D2.1 deliverable [6]). When applicable, it will be completed with vertical lines linking the exchange among service components (e.g. data on flight delay from Airport Collaborative Decision Making (A-CDM) goes to reschedule alert displayed to passenger).

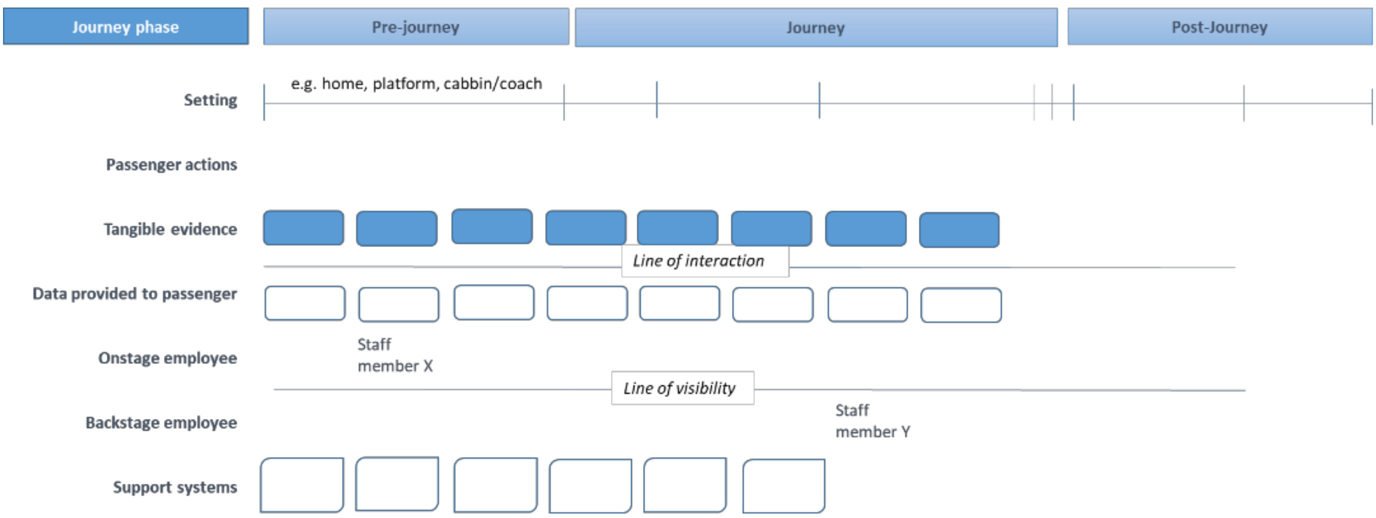

Figure 3 – Template for the X-TEAM D2D service blueprinting

The X-TEAM D2D service blueprint will be developed in details according to the project evolution and will be reported in the D3.2 "Concept of Operations for ATM integration in intermodal transport system [Concept Description]".

6 Technological enablers

Outcomes from the D2.1 document have been here considered as starting point (identification of barriers) to determine the needed technological enablers and their expected technological readiness levels according to the considered time horizons.

6.1 Technological enablers in the 2025/2035 timeframe

6.1.1 Enablers for digitalisation barriers

6.1.1.1 Air Transport (SATS, STOL, PATS, VTOL)

Barrier: Regulations and operational standards for aircraft intended to operate in UTM system (with regard to performance and equipment, both for manned and UAM).

Enabling projects:

- **SESAR Joint Undertaking Gulf of Finland U-space in cooperation with Volocopter [15]** – Demonstrations and tests validating that various systems are ready to safely and efficiently manage air taxi operations, their related services and subsequent interaction within existing aviation and airspace activities. Conformance with existing EASA regulations were maintained.

- **UAM Grand Challenge Program [16]** – The goal of the Grand Challenge program is to inform the codification of a "UML-4 book of requirements," or an understanding of what will be required to achieve a mature UAM ecosystem capable of operating efficiently in dense urban environments. Through a series of simulations and operational tests with industry and government partners, NASA also hopes to identify areas where further research is required in order to accelerate the timeline by which safe UAM operations can begin. During the tests, NASA and government partners will record a wide array of flight data, including acoustics, vehicle fight performance, charging, pre-departure scheduling and much more. That information will be provided to the FAA to help determine vehicle certification requirements and, for some data such as acoustics, back to the participating companies for their benefit.

Fulfilment of barriers: The given projects well address the issues of implementation of UAS for D2D travelling in an urban environment. The design and performance aspects of UAS in operational conditions, especially in vicinity of manned aviation, are under assessment. The results of the projects may throw the light on the certification issues of UAS.

Barrier: Regulations and standards for UTM systems integration with ATM with regard to flights management and sharing a common airspace.

Enabling projects:

- **PODIUM project [17]** – Its aim is to improve the links between the drone and the ATM communities, therefore contributing to a safer integration of drone operation in the European airspace and maximizing the outreach of the project at regulatory and standardization levels.

- **DLR Project City-ATM [18]** – Project aims include: development and assessment of a City-ATM-concept (density based airspace and traffic management); design of an open simulation- and demonstration platform; development and implementation of a UTM/CNS infrastructure for flight trails in urban airspace (e.g. Braunschweig, Hamburg).

- **PansaUTM [19]** – One of world's first national operational UAS traffic management/air traffic management (UTM/ATM) systems to coordinate drone flights in controlled airspace and to support drone pilots in all areas of a national airspace. The system is developed in Poland.

Fulfilment of barriers: The barrier is properly addressed. The projects aim to provide the interoperability of manned and unmanned aviation. However, the UAS the projects refer to are not dedicated to people transportation. The outcomes may deliver important suggestions for future advanced UAM services.

Barrier: Regulations and operational standards for vertiports, airports, heliports enabling safe and efficient automatic approach, landing and take-offs within integrated ATM/UTM system (including capabilities and limitations).

Enabling projects:

- **Skyports [20]** – An advanced air mobility company developing and operating landing infrastructure for the electric air taxi revolution, as well as operating cargo drone deliveries. Together with Volocopter company, it developed the prototype of vertiport in Singapore.

Fulfilment of barriers: The activities of this company lead to the increased number of regulations and standards for vertiports because it induces the regulatory actions as a result of the emergence of new infrastructure projects dedicated to UAM services. On the other hand, its effort has been focused only on vertiports, which are a fraction of UAM infrastructure.

Barrier: C2 and data link communication standards for aircraft operating in integrated UTM/ATM airspace enabling real-time traffic data for big number of aircraft (employing 5G cellular and sat technologies).

Enabling projects:

- **CMHK with SKY DRONE [21]** – Promoting 5G drone solutions to government agencies and large corporations who require drone deployments that perform tasks autonomously. This includes infrastructure monitoring, surveillance, cargo/delivery coupled with real-time artificial intelligence (AI) analysis of the data collected. New 5G deployments are subsidized by the Hong Kong government and are therefore in high demand all across the territory. International deployments on 4G/LTE as well as 5G networks are possible as well.

- **SESAR Deployment Manager with ADS-B [22]** – In high complexity environments such as the EU airspace, ADS-B is envisaged to operate in conjunction with existing independent cooperative chains, greatly enhancing accuracy, data availability and reducing frequency load.

Fulfilment of barriers: The projects respond to the global demand for a high efficiency, low latency and high-performance solutions for communication link in aviation industry. As limited number of terrestrial ground stations and space systems of 5G network exist for commercial use nowadays, there is little knowledge and experience about the implementation of 5G based systems on a mass scale in integrated UTM/ATM services.

Barrier: Implementation of geo-awareness and geo-fencing technologies in integrated UTM/ATM airspace (e.g. assuring separation from prohibited areas like CAT airport). As well as avoiding of adverse weather conditions.

Enabling projects:

- **AirMap [23]** – The company delivers tools for geo-awareness, such as geofencing, geo-caging & traffic alerts linked with digital and interactive map.
- **Fly Tech UAV Mission Manager, integrated with DroneRadar DAMS [24]** – The application delivers all aeronautical data specific to the local regulations including times of airspace activity. A unique feature of the system that creates the foundation for dynamic geofencing is online flight feasibility analysis with information on airspace availability and required ATC approvals and clearances. ATC can communicate with both drone and drone operator any time during the mission by broadcasting information such as temporary flight permission, restrictions or the need to invoke a Fail-Safe procedure.
- **BMP388, by Bosch Sensortec GmbH [25]** – The compact device is for altitude stabilization in consumer drones, Internet of Things applications, vertical velocity indication, weather forecasting, health care applications, augmented reality (AR) and virtual reality (VR) devices, and enhanced GPS accuracy. The Bosch BMP388 digital barometric pressure sensor, available from Mouser Electronics, uses sensing principles to provide pressure and temperature measurements.

Fulfilment of barriers: The software and hardware solutions meet the goals for effective and safe geo-awareness that perform well for small UAS in uncongested environment. However, the projects do not cover the issues related to passenger flights. That is why more development must be done in the area of people transportation implementation into integrated UTM/ATM airspace.

Barrier: Development of independent on-board technologies for assuring other aircraft and ground obstacles separation.

Enabling projects:

- **SKY-Scanner [26]** – Development of an Innovative LIDAR Technology for New Generation ATM Paradigms. The main goal of the project was to develop a novel laser tracking technology (SKY-Scanner System) capable of detecting and tracking aircrafts up to at least 6 nautical miles from the ATZ barycentre, namely a facility of enabling techniques, protocols, numerical prediction tools and devices specifically designed for the analysis of the laser systems performances in ATC applications.
- **Casia 360, by Iris Automation [27]** – A computer vision-based UAV detect-and-avoid system that enables safe and reliable BVLOS operation. The combined hardware and software solution utilizes state-of-the-art industrial cameras to provide full situational awareness to sense and detect obstacles and other aircraft. A sophisticated computing platform, based around the NVIDIA Jetson TX2 and the Casia 360 proprietary intelligent algorithms, makes rapid real-time decisions and determines the safest course of action to avoid collisions.

- **Miniature Next-Generation ADS-B Technology (Transceivers/ Receivers), by Aerobits [28]** – The company is specialized in miniature avionics technologies for unmanned aerial vehicles (UAVs) and drones. Such hardware and software solutions facilitate the integration of unmanned aerial systems (UAS) into civilian airspace, following the guidelines laid down by aviation authorities throughout the world.

- **DroneWatcherRF, HARRIER DSR, by DroneWatcher [29]** – It delivers hardware and software solutions for tracking UAS based on their RF signatures or data from military-grade solid-state Doppler radar (no RF or GSP signature needed).

Fulfilment of barriers: The barrier is properly addressed. The given technologies provide vast and robust solutions for ground obstacles and aircraft separation, assuring the safe and uninterrupted flights.

Barrier: Standards and requirements and procedures for manned aircraft flight control systems operating within UTM airspace covering manned aircraft flight automation and HMI.

Enabling projects:

- **Autonomous Taxi, Take-Off and Landing (ATTOL), by Airbus [30]** – The ATTOL project was initiated by Airbus to explore how autonomous technologies, including the use of machine learning algorithms and automated tools for data labelling, processing and model generation, could help pilots focus less on aircraft operations and more on strategic decision-making and mission management. Airbus is now able to analyse the potential of these technologies for enhancing future aircraft operations, all the while improving aircraft safety, ensuring today's unprecedented levels are maintained.

Fulfilment of barriers: The project proves the feasibility of transforming the manned passenger aircraft into the unmanned vehicle by utilizing AI algorithms and HMI that automate the flight. Comprehensive analysis and regulations of such systems must be conducted and developed to ensure maximum level of safety.

6.1.1.2 Road Transport (personal transport, public transport, shared mobility)

6.1.1.2.1 Road Transport (Personal transport - Electric car, Autonomous car)

Barriers for Personal transport - Electric car:

- **Communication technologies assuring high speed access to large number of users in considered area enabling creation of accurate traffic patterns forecast in a day-scale. Realized by portable or car-integrated devices.**
- **Deployment and integration with necessary infrastructure like charging stations, traffic lights, parking sites, etc.**

Barriers for Personal transport - Autonomous car:

- **Communication technologies assuring high speed access to large number of users in considered area enabling creation of accurate traffic patterns forecast in a day-scale. Realized by portable or car-integrated devices.**

- **Regulations and standards covering safe operation in non-mixed environment (separated autonomous traffic) covering aspects of risk mitigation and procedures for occurrence severity minimization/optimization.**
- **Development of technologies concerning two-way V2V, V2I, V2X communication enabling safe and sustainable operations in non-mixed environment (autonomous traffic only).**
- **Deployment/adapting of necessary infrastructure enabling V2V, V2I, V2X communication in areas (roads, lanes, etc.) dedicated to autonomous traffic.**

Enabling projects:

- **Research for TRAN Committee [31]** – This study analyses the various challenges of the deployment of charging infrastructure within the EU. This includes existing technologies and standardization issues, metering systems and pricing schemes, business and financing models, the impact of charging infrastructure on the dissemination of Personal Electric Vehicles (PEVs), and the appropriateness of current technologies, business models, and public policies. This study relates to charging points for electric cars, vans, buses, and bikes.
- **5G PPP [32]** – The challenge of this project is to eliminate the current and anticipated limitations of network infrastructures, by making them capable of supporting a much wider array of requirement than is the case today and with capability of flexibly adapting to different "vertical" application requirements. The vision is that, in ten years from now, telecommunication and related general-purpose IT services will be integrated in a common very high capacity and flexible 5G ubiquitous infrastructure, with seamless integration of heterogeneous wired and wireless capabilities.
- **FANTASTIC-5G [33]** – The overall objectives of the project are (condensed):
  - To develop a flexible and scalable multi-service air interface, with ubiquitous coverage and high capacity where and when needed, being highly efficient in terms of energy and resource consumption, being future-proof and allowing for sustainable delivery of wireless services far beyond 2020.
  - To evaluate and validate the developed concepts and build up consensus on reasonable options for 5G standardization.

Fulfilment of barriers:

These projects adequately cover the aspects of regulations and standards in terms of charging infrastructure deployment and 5G technology for fast and reliable communication assuring high speed access to a large number of users. Furthermore, aspects of wireless machine to machine communication technologies giving speed highly efficient access to large number of users enabling development of V2V, V2I and V2X communication is well covered.

6.1.1.2.2 Road Transport (Public transport - Autonomous bus, Transit Elevated bus; Shared mobility - electric autonomous car, shared micromobility)

Barriers for Public transport - Autonomous bus, Transit Elevated bus; Shared mobility – electric autonomous car:

- **Communication technologies assuring high speed access to large number of users in considered area enabling creation of accurate demand patterns forecast in a day-scale as well as resulted transport resources allocation and time-table. Realized by portable passenger devices and bus installed sensors.**

- **Regulations and standards covering safe operation in non-mixed environment (separated autonomous traffic) covering aspects of risk mitigation and procedures for occurrence severity minimization/optimization.**
- **Development of technologies concerning two-way V2V, V2I, V2X communication enabling safe and sustainable operations in non-mixed environment (autonomous traffic only).**
- **Deployment/adapting of necessary infrastructure enabling V2V, V2I, V2X communication in areas (roads, lanes, etc.) dedicated to autonomous traffic.**

Barriers for Shared mobility – shared micromobility:

- **Communication technologies assuring high speed access to large number of users in considered area enabling creation of accurate traffic patterns forecast in a day-scale. Realized by portable or car-integrated devices.**
- **Deployment and integration with necessary infrastructure like charging stations, traffic lights, parking sites, etc.**

Enabling projects:

- **Green eMotion [34]** – The project aims at enabling mass deployment of electromobility in Europe. The Smart Grids development, innovative ICT solutions, different types of electric vehicles (EV) as well as urban mobility concepts are considered for the implementation of this framework. The project contributes to the improvement and development of new and existing standards for electromobility interfaces.
- **Autonomous Vehicles & Traffic Safety [35]** – The project provides a synthesis of current knowledge and a discussion on current and future challenges of connected and autonomous vehicles regarding traffic safety. This aim is achieved through a critical analysis of the current scientific literature and technical and policy reports, thus providing a snapshot of the state-of-the-art and outlining the next steps that will have to be undertaken to ensure a safe transition into connected fleets and gradually increasing automation levels.
- **Regulations for on-road testing of connected and automated vehicles: assessing the potential for global safety harmonization [36] –** This paper reviews the main safety and liability issues for CAVs with a focus on the rules developed for on-road testing to date in Australia, the United States, and Germany. It also reviews government policies from Victoria, Australia, and California, the United States, and it provides an appendix on European Union (E.U.) regulations.
- **Intermediate Report on V2X Business Models and Spectrum [37] –** The objectives of the spectrum study in 5GCAR (5G Communication Automotive Research and innovation) are:
  - to establish a comprehensive and up-to-date understanding of the spectrum resources usable for V2X communications;
  - to perform suitability analysis of spectrum resources for V2X communications;
  - to identify spectrum usage alternatives supporting V2X use cases selected by 5GCAR.
- **Study on the Deployment of C-ITS in Europe [38] –** The outputs of the study provide guidance for relative impact of different bundles of cooperative C-ITS (Cooperative Intelligent Transport Systems) and paces for deployment. It contributes to the development and the C-ITS Platform of a strategy in the form of a Commission Communication on the deployment of C-ITS in the EU.

Fulfilment of barriers:

All the given projects refer to the public transport mobility and its regulatory aspects in terms of communication technologies, infrastructure adaptation and V2V, V2I and V2X communication demand. Detailed legislation issues and harmonized safety and on-road testing standards are thoroughly covered.

6.1.1.3 Rail Transport - Autonomous rail wagon / Automated Guided Vehicle (AGV)

Barrier: **Communication technologies assuring high speed access to large number of users in considered area enabling creation of accurate demand patterns forecast in a day-scale as well as resulted transport resources allocation and time-table. Realized by portable passenger devices and railroad vehicles installed sensors.**

Enabling projects:

- **RIDE2RAIL [39]** – The project will integrate public, private and social data sets and sources and existing transport platforms to improve the ride-sharing experience. This will allow users to compare and choose between multiple modes of transport based on travel time, comfort, cost and environmental impact. The project will deliver proposals rolled out in four cities in Europe: Padua, Athens, Brno and Helsinki.
- **MaaSive [40] –** The project focuses on integrating new technologies to improve railway travel experience. It addresses passenger service platform specifications for an enhanced multi-modal transport eco-system including Mobility as a Service (MaaS).
- **ATTRACkTIVE [41] –** The project addresses a system that will guide, support, inform, and even entertain users throughout their entire itinerary, adapting to unforeseeable interruptions and events in order to propose alternative routes, including in the first and last miles. It aims to implement both the Shift2Rail Trip Tracker and Travel Companion, two major components to materialize this vision and deliver seamless door-to-door travel support encompassing both public and private transportation portions of a journey. This includes disruption handling, navigation and user centric ubiquitous applications as well as the required tooling and modular design to foster adoption and enable future refinements, new concepts and ideas.
- **Shift2Rail [42] –** Cutting disruptions and infrastructure inconsistencies between EU countries, improving flexibility, boosting high-speed connections and making rail cost-competitive are vital to tempt people to make this shift. Shift2 Rail will create rail-centered mobility as a service and on-demand service and develop on-demand service with an adaptive supply**.**
- **IP4MaaS - Shift2Rail IP4 to support the deployment of Mobility as a Service [43] –** IP4MaaS will demonstrate the technologies at an unprecedented level: six different locations in Europe including more than ten transport operators (public transport and Mobility-as-a-Service), authorities and agencies. The 'Booking & Ticketing' will include multiple but parallel interactions with several booking, payment and ticketing engines, including the all-important roll-back activities, should any single transaction fail, in order to eliminate risk.
- **ExtenSive - Extending the attractiveness of transport for end user and extending IP4 to SaaS solutions [44] –** The project provides complementary and continuous solutions already started within previous projects, (MaaSive, ATTRACkTIVE, Co-Active and the lighthouse project IT2Rail), to enhance the traveler experience and improve travel services (in the areas of travel

shopping, trip tracking, booking and ticketing and aligned with Mobility as a Service paradigms), and deal with Software as a Service approach.

Fulfilment of barrier:

Technological solutions and ICT platforms presented in the aforementioned projects comprehensively respond to the barrier. By utilizing modern communication technology, e.g. 5G, it will be possible that customers easily plan, book and purchase door-to-door journeys without dealing with different tools, procedures and interfaces, at the same time enabling the creation and planning of journey patterns. Thus, transport on-demand, congestion elimination, smooth travelling among different modes of transport will be delivered.

Barrier: Regulations and standards covering safe operation in non-mixed environment (separated autonomous traffic) covering aspects of risk mitigation and procedures for occurrence severity minimization/optimization.

Enabling projects:

- **MODSafe (Modular urban transport safety and security analysis) [45] –** consortium aims at providing for the first time a coherent and agreed Hazards Analysis and Risk Analysis.

Fulfilment of barrier:

The analyses made in this project will reflect to the assumptions in the barrier in terms of risk mitigation and procedures for occurrence severity minimization/optimization by creation of a functional and Object Safety Model of an urban guided transport system.

Barrier: Deployment/adapting of necessary infrastructure enabling V2V, V2I, V2X communication in areas (rails, terminals, etc.) dedicated to autonomous railroad traffic.

Enabling projects:

- **Shift2Rail IP2 (TD 2.7) [46]** – The project aims to overcome the shortcomings in the current European Train Control System (ETCS) and Communications-Based Train Control (CBTC) and deliver an adaptable train-to-ground communications system usable for train control applications in all market segments, using packet switching/IP technologies (GPRS, EDGE, LTE, Satellite, Wi-Fi, etc.).
- **Shift2Rail IP2 (TD 2.1) [46]** – The development of a new Communication System aims to overcome the shortcomings in the current European Train Control System (ETCS) and Communications-Based Train Control (CBTC) and deliver an adaptable train-to-ground communications system usable for train control applications in all market segments, using packet switching/IP technologies (GPRS, EDGE, LTE, Satellite, Wi-Fi, etc.).
- **PERFORMINGRAIL [47]** – The project will support the activities of the adaptable communications technology demonstrator, by helping to bring the developments as close as possible to the market and also by helping to update the regulatory framework.
- **AB4Rail [48]** – The project aims to identify and select alternative communication bearers, as well as, select proper communication protocols for the adaptable communication system of the Shift2Rail technical demonstrator.
- **LINX4RAIL-2's [49]** – System Architecture and Conceptual Data Model For Railway, Common Data Dictionary And Global System Modelling Specifications.

Fulfilment of barrier:

The barrier is well addressed by a series of new communication solutions in these projects that will allow for an interrupted and smooth interface between V2V, V2I, V2X users in an automated way.

6.1.1.4 Water Transport (Autonomous ferry)

Barrier: Regulations and standards for autonomous water transport systems integration with manned water transport with regard to traffic management and sharing a common area.

Enabling projects:

- **AutoFerry, by NTNU [50]** – The main hypothesis of the project is that such ferries can operate safely alongside other vessels in confined and congested environments such as urban water channels. Verifying this requires a broad multi-disciplinary approach, where the research methods combine theory, simulations and experimental testing and validation.

Fulfilment of barrier:

- The **AutoFerry** project will deliver essential information about the integration of autonomous ferries with manned units. The outcomes of the project will lay the foundations for the development of operation and safety standards.

Barrier: Implementation of geo-awareness and geo-fencing technologies in integrated water transport (e.g. assuring separation from prohibited zones).

Enabling projects:

- **Seaaware, by Kongsberg [51]** – The system combines multiple sensors with intelligent software and Situational Awareness is designed to mitigate the risks navigators face, especially in poor weather conditions, congested waters or at night. Essentially, it gives the master and bridge personnel a supreme understanding of the ship's surroundings.
- **Falco [52]–** Rolls-Royce and Finferries Fully Autonomous Ferry with situational awareness capabilities. Fusing sensor data is relayed to Finferries' remote operating centre on land, where the captain monitors the autonomous operations with possibility of taking control of the vessel if necessary.
- **Marine Tractor Beam, by VTT SENSEWAY [53]–** A platform that provides situational awareness as a service for vessels by digitalizing the real world and enabling the enhanced traffic monitoring and control for ports and other shore-based operators.
- **MarineTraffic [54]**– The system displays near real-time positions of ships and yachts worldwide. Using the largest network of land-based AIS receivers, the app covers most major ports and shipping routes.
- **Automatic Identification System (AIS) [55]** – The AIS is a maritime communications device. It uses the very high frequency (VHF) radio broadcasting system to transfer data. AIS equipped vessels (shipborne AIS) and shore-based stations (non-shipborne AIS) can use it to send and receive identifying information.

Fulfilment of barrier:

The projects respond to the demand for geo-awareness and geo-fencing systems and thus assure the separation from prohibited zones by combination of onboard and wireless (cellular and satellite) systems.

Barrier: Regulations and operational standards for autonomous ferries intended to operate (with regard to performance and equipment).

Enabling projects:

- **YARA BIRKELAND, by Kongsberg [56] –** The vessel YARA Birkeland will be the world's first fully electric and autonomous container ship, with zero emissions. KONGSBERG is responsible for development and delivery of all key enabling technologies including the sensors and integration required for remote and autonomous ship operations, in addition to the electric drive, battery and propulsion control systems.
- **Ships Doctor, by Kongsberg [57] –** A generic end-to-end platform for secure collection, transfer, storage and analysis of ship data. This gives customers real-time access to key information about the health of their onboard equipment and systems. As well as a mobile dashboard on the ship, the same information is sent through a customer portal on shore.
- **Autocrossing system, by Kongsberg [58]** – Autocrossing optimizes acceleration, transit and deceleration phases for different vessel loads and weather conditions while keeping to agreed departure times and crossing durations.

Fulfilment of barrier:

The solutions provide the required information about ship's technical condition and its operational capabilities by analyzing data from sensors and providing the optimized parameters for the cruise. Their implementation on a mass scale will need a regulatory work to encompass the critical issues related to the performance and equipment of autonomous ferries.

Barrier: Regulations and operational standards for ports, piers or marinas enabling safe and efficient automatic approach, and mooring (including capabilities and limitations).

Enabling projects:

- **MoorMaster NxG, by Cavotec [59] –** Cavotec's combined MoorMaster™ automated mooring technology and Automatic Plug-in System (APS) is a single revolutionary platform that enables the fast, safe and efficient mooring and charging of e-vessels.
- **SenseTime [60] –** The system uses ultra-high-resolution cameras and a graphic processing unit (GPU) to automatically identify vessels in the surrounding area. The image recognition technology could be used to monitor shipping lanes, as well as for security and coastguard operations.

Fulfilment of barrier:

The approach and mooring process of autonomous and manned water units may be conducted efficiently with these technological solutions. The barrier is well addressed, however regulations regarding the parameters and metrics for safe approach and mooring must be established.

Barrier: C2 and data link communication standards for water vehicles enabling real-time traffic data for big number water vehicles (employing 5G cellular and sat technologies).

Enabling projects:

- **Fjord 5G [61]** – The new mobile radio standard 5G is expected to enable passenger ferries to cruise partly autonomously between the banks of the inner Kiel Fjord and later even in a fully autonomous way.
- **WMS [62] –** Emergence of low and medium earth orbit satellites, a host of new capabilities, will enable cruise lines to enhance guest and crew experiences, improve marine safety and operations, and contribute to the industry's environmental sustainability efforts. 5G cellular mobile is a game-changer for cellular mobile and is a game-changer for cruise lines and how they use mobile connectivity onboard their ships, not just for passengers but for every part of their cruise ship operation.

Fulfilment of barrier:

The projects aim at utilizing the 5G network together with LEO satellites (providing greater coverage areas, especially over the oceans) in the maritime applications and meet sufficiently the objectives of the barrier.

Barrier: Development of independent on-board technologies for assuring other boats, ships etc. and ground obstacles separation.

Enabling projects:

- **Seaeye, Proximity view, by Kongsberg [63] –** SeaEye can be delivered with precise optical parameters describing each camera for optical navigation. These parameters, together with mechanics tested and approved for the rough maritime environment, enable pixel precision when integrating the platform into a machine vision application. ProximityView offers full 360 degrees camera coverage of the proximity zone fusing sensor data into the view, such as: objects, distances, velocities, acceleration, system status and planned path.

- **The ReVolt, by DNV GL [64] –** The autonomous, fully battery powered vessel will serve as test bench in researching sensor fusion and collision avoidance for autonomous surface vehicles.

- **Automatic Identification System (AIS) [55] –** The AIS is a maritime communications device. It uses the very high frequency (VHF) radio broadcasting system to transfer data. AIS equipped vessels (shipborne AIS) and shore-based stations (non-shipborne AIS) can use it to send and receive identifying information.

Fulfilment of barrier:

The solutions assure the separation from other vessels and ground obstacles by a combination of onboard and wireless (cellular and satellite) systems. Interoperability of them may provide a required level of safety.

Barrier: Standards, requirements and procedures for manned water vehicles operating in nearing of autonomous ferry area and HMI.

Enabling projects:

- **Marine Tractor Beam, by VTT SENSEWAY [54] – A** platform that provides situational awareness as a service for vessels by digitalizing the real world and enabling the enhanced traffic monitoring and control for ports and other shore-based operators.

- **AutoFerry, by NTNU [50] –** Among other objectives of the project, it aims at development of anti-collision system and safe remote-control HMI.

Fulfilment of barrier:

The barrier is properly addressed by the projects that provide the control solution over the vessels by digitizing the way they move. Equipping the manned vessels with sensors and communication devices, it is possible to coordinate ships, regardless of whether they are manned or unmanned. It is required to standardize the digitization process of all manned vessels.

6.1.2 Enablers for technological barriers

6.1.2.1 Air Transport (SATS, STOL, PATS, VTOL)

Barriers for SATS, STOL:

- **Operational cost and energy consumption in comparison to surface transport.**
- **Pollution/emission free operations - Electric propulsion technology assuring economic justification for it (mainly fuel cell energy density).**
- **Technical reliability of UAM vehicle components – strong need for cost efficient improvement.**
- **Weather resilience. Providing possibility to safety operate during adverse weather conditions (turbulent, icing, Instrumental Meteorological Conditions (IMC)).**
- **Exposition to noise. Development of silent propulsion technologies, especially with regard to operation of heavier aircraft over populated areas.**
- **On-board bird-deterrence technologies to mitigate bird strike risk.**

Enabling projects:

- **SAT-Rdmp [65]** – The Small Air Transport (SAT) focuses on the new mode affordable, accessible, energy effective component of Air Transport System. It fills the niche between Surface and Scheduled Air Transport.

- **Zunum Aero [66]** – Range-optimized hybrid-to-electric aircraft bring airliner economics to mid-sized aircraft, traveling over ranges from 700 miles in the early 2020s to over 1,000 miles by 2030. Flying point-to-point to thousands of secondary airports and feeders to hubs, the hybrids will power a distributed air system that complements the concentrated airliners and hubs of today. This will provide high-speed connectivity to every community, and bring fast, flexible, much more personalized travel.

- **Deicing Technology, by Battelle [67]** – Battelle has transformed in-flight aircraft ice protection with a proprietary technology based on resistive heating coating. This innovative anti-icing and deicing solution's small size, weight and power envelope are unmatched in the industry.

- **TKS® Ice Protection [68]** – The system is designed to be anti-icing but is also capable of de-icing, as TKS® fluid chemically breaks the bond between ice and frame, allowing the system to shed any accumulated ice and prevent any ice build-up thereafter.

- **DELICAT [69]** – The objective of DELICAT is to validate the concept of LIDAR based medium range turbulence detection, allowing efficient protection of the passengers and crew by actions such as seat belts fasten. The validation will be based on the comparison of the information on a turbulent atmospheric area, provided on one side by the remote LIDAR sensor and on the other side by the aircraft sensors (acceleration, air speed, temperature).

- **Airborne Doppler Lidar, by Mitsubishi [70]** – Airborne LIDAR system for detection of clear air turbulence (CAT).

- **Bird-X Technologies [71]** – The company offers bird repellent systems, utilizing sonic, ultrasonic and laser technologies.

<u>Fulfilment of barrier:</u>

The projects respond to the barriers by providing the adequate solutions and information. Utilizing those technologies, meeting the goals for safe, green and efficient flights will be more accessible.

<u>**Barriers for PATS, VTOL:**</u>

- **Development of efficient, reliable and affordable propulsion systems for VTOLs (e.g. rotors, conversion systems) as well as PATS.**

<u>Enabling projects:</u>

- **Heaviside, by Kittyhawk [72] –** Heaviside demonstrates the potential for a new type of accessible, all-electric air transportation. Propelled by eight variable-pitch electric propellers, Heaviside is a quick and quiet single-passenger vehicle that can take off and land in a 30 foot by 30-foot area that does not need to be paved.

- **Lilium Jet [73]** – The Lilium Jet balances high levels of efficiency with a noise footprint that is low enough to allow inner city operations. Distributed vectored thrust, delivered by 36 electric engines positioned across the airframe, allows for precision control of the aircraft during the most aerodynamically challenging phase of flight, when it transitions from hover flight to forward, wing-borne flight.

- **Volocopter [74]** – The eVTOL features multiple redundancy systems, ensuring a virtually failsafe aircraft. The redundant systems include rotors, electric motors, batteries, avionics and display.

- **Joby Aviation [75]** – Powered by six electric motors, the aircraft takes off and lands vertically, giving the flexibility to serve almost any community. It aims at providing aerial ride-sharing services that combine the ease of conventional ridesharing with the power of flight.

- **Zero Avia [76]** – ZeroAvia enables zero emission air travel at scale, starting with 500 mile short-haul trips, at half of today's cost. The Novel approach removes many limitations of the current zero emission programs.

Fulfilment of barrier:

The examples of presented aircrafts are a great response to the barrier that pays attention to eco-friendly, quiet, efficient and reliable propulsion technologies.

Barriers for Certification of SATS, STOL, PATS, VTOL:

- **Certification burden and cost, especially for disruptive solutions (e.g. limited suitable regulations and standards referring strictly to new types of aerial vehicles: SATS, STOL, VTOL, PATS).**
- **Certification requirements for Electric and/or Hybrid Propulsion System (EHPS) in any manned and unmanned aircraft.**
- **Lack or initial development of standards for larger units.**
- **Regulations for certification bodies and research infrastructure/ development certification able to cope with large number of applications.**
- **Limited regulations to Special condition SC-VTOL-1 with technical specifications and airworthiness standards for type certification process of small vertical take-off and landing (VTOL) aircraft including aircraft with a passenger seating configuration of 9 or less and a maximum certified take-off mass up to 3175 kg.**
- **Regulations and standards for design, operations of larger VTOLs (more than 9 passengers' seats).**
- **Initial and continuing airworthiness.**

Enabling projects:

- **Zunum Aero [77] –** The projects aiming to introduce electric or hybrid-electric aircraft to market are underway to the certification process.
- **Heaviside by Kittyhawk, Joby Aviation ([72],[78]) –** These VTOLs being developed in USA get prepared for the certification process under the rules of FAA.
- **Lilium Jet [79] –** A German company aircraft undergoing the European Law and its certification process is under the EASA regulations.
- **Volocopter [80] –** First Air Taxi developer to be awarded SC-VTOL Design Organization Approval by the European Aviation Safety Agency.

Fulfilment of barrier:

With an emergence of new and innovative types of aircrafts, the need for new regulations and standards has appeared as urgent. Therefore, as the barriers are not directly addressed by these aircraft projects, they impose the necessity for new regulatory actions concerning SATS, STOL, PATS, VTOL vehicles.

Barriers for Infrastructure for air transport:

- **Regulations for the dedicated infrastructure of vertiports covering: guides for airport winter safety, operations, plowing, deicing and anti-icing issues, guidelines for all-weather VTOL facilities (i.e., heliports and helistops with precision instrument approach capability), limitations due to unpredictable atmospheric conditions due to climate change and weather phenomena intensification or fire protection requirements.**
- **Definition of regulations regarding location of landing sites in urban areas (covering approach safety – ground obstacles, birds' habitats, turbulences around buildings).**

Enabling projects:

- **Skyports [20]** – An advanced air mobility company developing and operating landing infrastructure for the electric air taxi revolution, as well as operating cargo drone deliveries. Together with Volocopter company, it developed the prototype of Voloport in Singapore.

Fulfilment of barriers:

The barrier is not directly reflected by the activity of this company but it is a driver for new regulations and standards emergence concerning UAM infrastructure design and deployment strategy.

6.1.2.2 Road Transport (personal transport, public transport, shared mobility)

6.1.2.2.1 Road Transport (Personal transport - Electric car)

Barriers:

- **Electric propulsion efficiency capacity and life duration of available fuel cells.**
- **Technologies allowing for fast charging.**
- **Standards and requirements for charging stations.**
- **Standards and regulations covering safety requirements to be imposed on electric car.**
- **Technology progress decreasing cost of purchasing and operation of electric car**

Enabling projects:

- **Batteries on wheels: the role of battery electric cars in the EU power system and beyond [81] –** This study builds onto the EV deployment scenarios previously developed by Element Energy for the European Climate Foundation, combining the EU's push to limit the emissions of new vehicles and feedback from car OEMs.
- **Circular Economy Perspectives for the Management of Batteries used in Electric Vehicles [82] –** The objective of the project is to provide a strong factual base and techno-economic analysis to address the following questions: What are the current available and emerging techniques in the manufacturing, re-use and recycling of traction batteries for electric vehicles? What are the perspectives for developing a sustainable value chain for electric vehicle batteries in the EU? What are the current strengths and weaknesses of the EU economy (industry,

infrastructure, policy framework) for dealing with the lifecycle of traction batteries in the perspective of road transport electrification?

- **Research on Factors That Influence the Fast Charging Behaviour of Private Battery Electric Vehicles [83] –** This research was made to understand BEV charging behaviour and its influential factors. Considering the urgency of BEV charging, BEV drivers tend to choose fast charging when BEV is in driving state.
- **Advanced Electric Vehicle Fast-Charging Technologies [84] –** Clearly, the need for fast charging exists for consumer convenience as to not limit drivers to the daily average driving distance (31.5 miles/day), while also improving the energy transfer rate to closer values to that of gasoline and diesel refuelling stations. Therefore, the scope of this review paper is super-fast charging (Level 3 charging, energy transfer rates >50 kW).
- **Research for TRAN Committee [31] –** This study analyses the various challenges of the deployment of charging infrastructure within the EU. This includes existing technologies and standardization issues, metering systems and pricing schemes, business and financing models, the impact of charging infrastructure on the dissemination of PEVs, and the appropriateness of current technologies, business models, and public policies. This study relates to charging points for electric cars, vans, buses, and bikes.
- **Update on electric vehicle costs in the United States through 2030 [85] –** This working paper assesses battery electric vehicle costs in the 2020-2030 time frame, collecting the best battery pack and electric vehicle component cost data available through 2018. The assessment also analyses the anticipated timing for price parity for representative electric cars, crossovers, and sport utility vehicles compared to their conventional gasoline counterparts in the U.S. light-duty vehicle market.

Fulfilment of barrier:

Presented projects fully respond to barriers defined for electric cars. Issues related to infrastructure, fuel cells, fast charging technology, regulations and policy are well recognized and described.

6.1.2.2.2 Road Transport (Personal transport - Autonomous car, Public transport - Autonomous bus, Shared mobility – electric autonomous car)

Barriers:

- **Availability of reliable onboard technologies assuring separation from obstacles, pedestrians or other vehicles enabling autonomous drive in non-mixed environment (on dedicated infrastructure).**
- **Standards and regulations covering requirements to be imposed on autonomous car and buses in non-mixed traffic (concerning onboard equipment).**
- **Standards and recommendations for dedicated infrastructure assuring safe operation of autonomous cars and buses (covering road signs, road specification, necessary equipment).**
- **Security aspects. Driver free autonomous buses seems to be more vulnerable to terrorist attack or vandalism act.**

Enabling projects:

- **The r-evolution of driving: from Connected Vehicles to Coordinated Automated Road Transport (C-ART) [86] –** Some kind of central management may become necessary in order

to guarantee that the full system benefits of road transport automation can be reaped. Coordinated automated and connected vehicles (Coordinated Automated Road Transport, C-ART) are investigated in this study as they could contribute to avoid possible negative consequences of road automation and enable a safe low emission mobility.
- **Autonomous Vehicle Implementation Predictions Implications for Transport Planning [87] –** Report explores issues like: how autonomous (also called self-driving or robotic) vehicles (AVs) will affect future travel, and therefore the need for roads, parking facilities and public transit services, and what public policies can minimize the problems and maximize the benefits of these new technologies.
- **FULLY AUTONOMOUS VEHICLE-BORNE IMPROVISED EXPLOSIVE DEVICES – MITIGATING STRATEGIES [88] –** This thesis overviews the projected threat posed by the nefarious use of fully autonomous vehicles as fully autonomous vehicle-borne improvised explosive devices. It is shown how easily autonomous vehicles can be used for explosive delivery and discusses technological solutions that should be implemented, proactively, to reduce this threat

Fulfilment of barrier:

Autonomous transport systems, technology which they use and regulations which they need is well and clearly shown in enabling projects. However, security aspects may not be sufficient as they are considered for only one possible scenario.

6.1.2.2.3 Road Transport (Shared mobility – shared micromobility)

Barriers:

- **Development of standards and recommendations for dedicated infrastructure. Safe, efficient and separated from motorized traffic.**
- **Integrating of dedicated infrastructure (e.g. bicycle path network) with change nodes including airports.**
- **Weather conditions – climate related limitations.**
- **Lack of ability to transport baggage.**

Enabling projects:

- **Small is beautiful [89] –** E-scooters and dockless bicycles appeared in cities' bike lanes suddenly and in great numbers, showing a real demand for single-occupant vehicles—and creating challenges for both providers and government agencies.
- **Micromobility and public transport integration [90]** – This paper is a review of studies that focus specifically on the integration of micromobility and public transport systems.
- **Living lab e-micromobility - MOBY [91] –** E-micromobility should be seen as a new mode of transportation, that responds to a widespread demand for multimodal urban transport. This conclusion points to a need for conceptualizing perspectives and possible regulative frameworks, which could enable micromobility to become a significant part of an open-to-public multimodal system.

Fulfilment of barrier:

Available projects answer to barriers especially in terms of micromobility, not in particular focused on shared mobility but still giving a great view for this type of transportation and its features.

6.1.2.3 Rail Transport - Autonomous rail wagon / AGV

Barriers:

- **Standards and recommendations covering traffic organization minimizing risk of interaction of autonomous tramway with road users, pedestrians.**
- **Standards and recommendations covering inclusive design of tramway stops or metro stations minimizing the risk of unintended passenger behavior and occurring of dangerous situations undetectable by the system.**
- **Development of technologies related to sensing of potentially dangerous situation (e.g. image analysis, behavior analysis).**
- **Security aspects.**

Enabling projects:

- **Shift2Rail IP2 - Safe Train Positioning (TD 2.4) [92] –** The project aims to develop a fail-safe, multi-sensor train positioning system (applying Global Navigation Satellite Systems (GNSS) technology to the current ERTMS/ETCS core and possible introducing an add-on for fulfilling the scope).
- **X2Rail-5 [93]** – Completion of activities for Adaptable Communication, Moving Block, Fail safe Train Localisation (including satellite), Zero on site Testing, Formal Methods and Cyber Security. The pillar (IP2) challenge is to increase functionalities of the existing signalling and automation systems and related design and validation processes providing a more competitive, flexible, real-time, intelligent traffic control management and decision support system, whilst addressing all four market segments and maintaining backward compatibility to the existing European Rail Traffic Management System (ERTMS) and especially its European Train Control System component (ETCS).
- **The MODSafe (Modular urban transport safety and security analysis) [45] –** The consortium aims at providing for the first time a coherent and agreed Hazards Analysis and Risk Analysis.
- **STREAM [94]** – Smart Tools for Railway work safety and performance improvement - will develop two smart technologies employing environment perception and human intention principles, enabling prevention and risk mitigation.

Fulfilment of barrier:

Barriers for autonomous rail wagon and theirs impact on its future deployment are clearly taken under consideration in presented projects which give complete knowledge of incoming challenges.

6.1.2.4 Water Transport (Autonomous ferry)

Barrier: **Standards and recommendations for inclusive design and specification of dedicated safe infrastructure like piers, mooring systems.**

Enabling projects:

- **MoorMaster NxG, by Cavotec [59] –** Cavotec's combined MoorMaster™ automated mooring technology and Automatic Plug-in System (APS) is a single revolutionary platform that enables the fast, safe and efficient mooring and charging of e-vessels
- **Leixões Cruise Terminal [95] –** The strategic definition of a new cruise terminal had a double objective: improvement of the commercial efficiency and a better urban integration. That's why the project integrates new buildings, berthing work and exterior spaces of public vocation. The main building shelters several programmatic components: cruise ship terminal, marina facilities, the Science and Technology Park of the Sea of the University of Porto, event rooms and a restaurant.
- **Pillars of Flux, by yankodesign [96]** – Pillars of Flux is a network of skyscrapers used as a vertical shipping port designed for expanding ports and emerging ports of tomorrow. The Pillars are detached from the city to free valuable shoreline for public use and its storage bodies are also designed vertically to save space on narrow gulfs and coves. Its interaction with the mainland is solely transportational, and its layout and pillar height depend on characteristics of the related city.

Fulfilment of barrier:

The presented solutions properly reflect to the barrier by delivering innovative architectural concepts as well as technological solutions to provide safe and effective infrastructure for water transportation.

Barriers:

- **Standards and recommendations for inclusive design and specification of ferries enabling safe and efficient travel.**
- **Development of safe, efficient and fast electrical propulsions including safe and environmental friendly fuel cells.**
- **On board technologies assuring separation from other ships, ferries, boats as well as water obstacles like shallows etc. with regard to onboard systems.**

Enabling projects:

- **Zeabuz Mobility System [97] –** The full Zeabuz mobility system includes the autonomous ferries, docking stations with wireless charging, passenger handling and ticketing systems, secure wireless communication and a remote support centre.
- **AutoFerry, by NTNU [50] –** The main goal of this project is to develop groundbreaking new concepts and methods which will enable the development of autonomous passenger ferries for transport of people in urban water channels.
- **DFDS hydrogen-powered ferry [98]** – The ferry will be powered by electricity from a hydrogen fuel cell system that emits only water and can produce up to 23 MW to propel the ferry, while it is expected to operate for DFDS' Oslo-Frederikshavn-Copenhagen route.

Fulfilment of barriers:

Appropriate response to the given barriers is found in above mentioned projects. New, ecologically friendly propulsion systems, innovative designs, technologies assuring separation from other vessels and objects are under development and during testing campaigns.

Barriers:

- **Definition of operational conditions assuring safe operation (concerning required water level, shallows, water current as well as weather conditions e.g. wind speed).**
- **Natural conditions. Both related to weather/climate issues like (freezing of water reservoir) and changing water levels.**
- **Security aspects.**
- **Standards and recommendations for operating of autonomous vehicles concerning ethics, definition of safest solution, minimization of risk or accident severity.**

Enabling projects:

- **MUNIN, D5.2: Process map for autonomous Navigation [99] –** This deliverable covers the issues of weather, safety and security aspects that affect the operational conditions of unmanned ship. Furthermore, the regulations corresponding to the given event related to the operation of the ship, are listed
- **Norled, hydrogen-powered car ferry [100] –** A hydrogen fuel cell powered ferry that is under development and to be deployed into Norwegian waters

Fulfilment of barriers:

The barriers are fully fulfilled by the presented projects that provide the details about sea ship operational parameters as well as the safety and risk issues of the maritime operations to assure safe, autonomous cruises.

6.2 Technological enablers in the 2050 timeframe

6.2.1 Enablers for digitalization barriers

6.2.1.1 Air Transport (SATS, STOL, PATS, VTOL)

Barrier: Implementation of regulations and operational standards for flexible UTM airspace enabling near real-time airspace and traffic management (covering sustainability issues, nowcasted demand for flights, as well as emergency, military or other public service operations prioritizing).

Enabling projects:

- **CORUS, U-space Concept of Operations [101]** – The project covers priority issues for flights within UTM infrastructure, depending on the mission type, human factor as well as traffic demand.

Fulfilment of barrier:

Since the project provides analysis and recommendations for regulations and standards only, the barrier is not directly addressed but it is a driver for regulatory implementation actions.

Barrier: Standards and regulations concerning AI procedures in case of appearing unintended, unexpected situation (covering risk mitigation and occurrence severity minimization/optimization).

Enabling projects:

- **AISA (AI Situational Awareness Foundation for Advancing Automation) [102]** – Implementation of AI into situational awareness determination. Shared situational awareness will be developed for a given traffic situation. ATM will be improved by using shared situational awareness while AI will, for example, be able to assess complex interactions between objects, draw conclusions and explain the reasoning behind them.
- **MITRE's Aviation Operations [103]** – MITRE's application of AI helps analysts recognize patterns in operational data, enhance analytics from multiple viewpoints, and connect data sets that provide insights at an extraordinary scale.
  The company develops machine learning frameworks to explore risk identification and future methods to assist in identifying potential new or emerging safety issues, then evaluating and validating these frameworks. The efforts cut across surface, terminal, and en-route operations to make aviation safer.

Fulfilment of barrier: The given projects cover the utilization of AI mainly in ATM applications. UAM or UTM services are not addressed by the mentioned projects hence the barrier is partially fulfilled.

Barrier: Availability of communication technologies providing ability to efficiently communicate all airspace users. Regulations and standards for 5G and beyond.

Enabling projects:

- **Starlink, by SpaceX; Kuiper, by Amazon; PointView's Athena, by Facebook; Iridium NEXT [104]** – LEO satellites providers. Thanks to the constellation of LEO satellites, it would be possible to support CNS technologies towards UAM applications. The satellites may also serve as relays for 5G transmission systems providing increased area coverage and decreased delay time. Moreover, LEO satellites may also be equipped with ADS-B receivers to provide the geo-awareness of UAS over unpopulated and distant areas.

Fulfilment of barrier: These undertakings allow for the extended use of satellite systems for communication purposes throughout the UTM and ATM services, making a great step towards effective and high-performance communication. What is more, they are the drivers for further regulatory actions.

Barrier: Implementation of algorithmic governance in order to assure efficient high-level management of air transportation as well as integration with other modes of transport.

Enabling projects:

- **AgentFly Technologies [105]** – Advanced software tools and algorithms for UAS operators, regulators and service providers:
  - trajectory planning in 4D,
  - geofencing,
  - avoidance of NFZ and other traffic for operation safety,
  - simulation of manned and unmanned traffic for fast verification,
  - integration of data from regulators, authorities, ANSP etc. for situational awareness,
  - design and verify cooperative and non-cooperative conflict detection and resolution algorithms.

Fulfilment of barrier:

The barrier is addressed in a limited scope, since the company offers the solutions for algorithmically assisted services of UAS mission planning and execution only within VLL airspace (small UAS, unintended for travelling purposes). Passenger flights, large cargo operations and integration with other modes of transport are not supported.

6.2.1.2 Road Transport (personal transport, public transport, shared mobility)

Barriers for personal transport – electric car:

- **As for 2035 and in addition the following considerations apply:**
- **Regulations and standards covering safe operation in mixed environment (manned and autonomous vehicles) covering aspects of risk mitigation and procedures for occurrence severity minimization/optimization.**
- **Driving support technologies (e.g. advanced automation or full automation in some situations) as two-way V2V, V2I, V2X communication enabling safe and sustainable operations in mixed environment (5G and beyond).**
- **Deployment of necessary infrastructure enabling V2V, V2I, V2X communication.**
- **Implementation of algorithmic governance in order to assure efficient high-level management of air transportation as well as integration with other modes of transport.**

Barriers for personal transport – autonomous car:

- **As for 2035 and in addition the following considerations apply:**
- **Regulations and standards covering safe operation in mixed environment (manned and autonomous vehicles) covering aspects of risk mitigation and procedures for occurrence severity minimization/optimization.**
- **Communication technologies enabling safe and sustainable operations in mixed environment (5G and beyond).**
- **Deployment of necessary infrastructure enabling V2V, V2I, V2X communication.**
- **Implementation of algorithmic governance in order to assure efficient high-level management of air transportation as well as integration with other modes of transport.**

Barriers for public transport, shared mobility – autonomous bus, transit elevated bus, electric autonomous car:

- **As for 2035 and in addition the following considerations apply:**
- **Regulations and standards covering safe operation in mixed environment (manned and autonomous vehicles) covering aspects of risk mitigation and procedures for occurrence severity minimization/optimization.**
- **Communication enabling safe and sustainable operations in mixed environment (5G and beyond).**
- **Deployment of necessary infrastructure enabling V2V, V2I, V2X communication.**
- **Implementation of automation in the area of e.g. fleet and resource management enabling high flexibility and delay-free answering on nowcasted demand for bus transport.**

- **Implementation of algorithmic governance in order to assure efficient high-level management of air transportation as well as integration with other modes of transport.**

<u>Barriers for shared mobility – shared micromobility</u>:

- **As for 2035 and in addition the following considerations apply:**
- **Regulations and standards covering safe operation in mixed environment (manned and autonomous vehicles) covering aspects of risk mitigation and procedures for occurrence severity minimization/optimization.**
- **Driving support technologies (e.g. advanced automation or full automation in some situations) as two-way V2V, V2I, V2X communication enabling safe and sustainable operations in mixed environment (5G and beyond).**
- **Deployment of necessary infrastructure enabling V2V, V2I, V2X communication.**
- **Implementation of algorithmic governance in order to assure efficient high-level management of air transportation as well as integration with other modes of transport.**

<u>Enabling projects:</u>

- **Autonomous Vehicle Implementation Predictions Implications for Transport Planning [87] -** Report explores issues like: how autonomous (also called self-driving or robotic) vehicles (AVs) will affect future travel, and therefore the need for roads, parking facilities and public transit services, and what public policies can minimize the problems and maximize the benefits of these new technologies.
- **A time of unprecedented change in the transport system [48] -** Based on the analysis of past and current trends, and the likely impacts of new developments under different scenarios, this report identifies ten priority areas for the UK government in terms of future solutions for many modes of transportation in 2040 and beyond time horizon.
- **Environmental Benefits of C-V2X for 5GAA - 5G Automotive [106] -** Study provides insights into the emission reduction potential of C-V2X (Cellular Vehicle to Everything communication) large-scale deployment including and beyond day 1 services. Emphasis is on communication to and from the vehicle. In particular, vehicle-to vehicle (V2V) and vehicle-to-infrastructure (V2I or I2V) applications
- **Paths of Automated and Connected Vehicle Deployment: Strategic Roadmap for State and Local Transportation Agencies [107] -** This research is aimed to formulate scenarios for automated and connected vehicles paths of deployment, examine how the plausible scenarios could affect state and local transportation agencies, and provide a strategic roadmap to assist these agencies in preparing for or responding to potential issues.

<u>Fulfilment of barrier:</u>

Barriers defined for road transport in 2050 timeframe are well recognized by presented projects. Proposed solutions, new design and technologies described in those papers provide answers to demands which are up to be relevant in future time horizon.

6.2.1.3 Rail transport – Autonomous rail wagon / AGV

<u>Barrier</u>: Regulations and standards covering safe operation in mixed environment (manned and autonomous vehicles) covering aspects of risk mitigation and procedures for occurrence severity

minimization/optimization, communication enabling safe and sustainable operations in mixed environment (5G and beyond).

Enabling Projects:

- **Safe4RAIL-3 [108]** will be based on the development of three technological pillars aimed at advancing the maturity of the technologies and devices for the next generation train control and monitoring system. Safe4RAIL-3 and its activities will be based on the development of three technological pillars aimed at advancing the maturity of the technologies and devices for the next generation for Train Control and Monitoring System (TCMS), in order to pass from prototypes level to TRL 6/7.
- **The AB4Rail project [109]** contributes to the work programme S2R-OC-IP2-02-2020 objectives by identifying alternative communication bearers (ABs) and communication protocols. The first study in AB4Rail will review the state of art of the considered alternative bearers to select the most promising ones for the Adaptable Communication System (ACS) technical demonstrator TD 2.1. The second study will investigate the optimal/best usage of the current and future communication protocols at application and transport levels for the ACS architecture.

Fulfilment of barrier:

A clear view on technology demands for future rail transport is provided in chosen projects both in relation to standards and regulations as well as in terms of future communication.

Barrier: Implementation of automation in the area of e.g. available resource management enabling high flexibility and nearly delay-free answering on nowcasted demand for train transport.

Enabling projects:

- **Shift2Rail IP2 [92]** - Smart radio-connected all-in-all wayside objects (TD 2.10). This TD aims to develop autonomous, complete, intelligent, self-sufficient smart equipment ('boxes') able to connect not only with control centres (e.g. interlocking) or other wayside objects and communicating devices in the area (by radio or satellite), but also, for instance, with on-board units. **Shift2Rail IP2** - **Safe Train Positioning** (TD 2.4) aims to develop a fail-safe, multi-sensor train positioning system (applying Global Navigation Satellite Systems (GNSS) technology to the current ERTMS/ETCS core and possible introducing an add-on for fulfilling the scope). It will enable the use of other new technologies (e.g. inertial sensors) or sensors (e.g. accelerometers, odometer sensors), to boost the quality of train localization and integrity information, while also reducing overall costs, in particular by enabling a significant reduction in all trackside conventional train detection systems (balises, track circuits and axle counters). A key challenge for **Shift2Rail IP2** is to enhance the advanced traffic management and control systems without impacting the ERTMS core, and where appropriate and necessary, to provide backwards compatibility to protect investments both in mainline and urban railways.
- **CO-ACTIVE (CO-modal journey re-ACcommodation on associated Travel serVices) [110]** provides the opportunity to focus specifically on those aspects of comodality whose level of customer-perceived risk discourages the advance purchase of comodal travel entitlements.

Fulfilment of barrier:

Solutions presented in those two enabling projects give sufficient answers for autonomous rail wagon demands which are expected in 2050 time horizon and beyond.

Barrier: Implementation of algorithmic governance in order to assure efficient high-level management of air transportation as well as integration with other modes of transport.

Enabling projects:

- **HYPERNEX - Hypernex: Ignition of the European Hyperloop Ecosystem [111]** addresses the need for a catalyst to accelerate the development of the fifth mean of transport, hyperloop, in Europe. A convergence of R&D entities, industry players, regulators and society need to be aligned with hyperloop developers.
- **My-TRAC [112]** fosters unprecedented involvement of users during, before and after a trip through a smart Human-Machine interface and numerous functionalities such as crowdsourcing, group recommendations, data exchange. The application implements a vast array of technologies, such as affective computing, Artificial Intelligence and user choice simulation, that fuse expertise from multiple fields. My-TRAC facilitates engagement of multiple stakeholders by seamlessly integrating services and creating connections between Rail operators, Mobility-as-a-Service and other PT providers.
- **DAYDREAMS [113]** objective is to move forward the integration and use of data and artificial/human trustworthy intelligence together with context-driven HMI for prescriptive intelligent asset management systems in railway.
- The scope of **GoF4R (Governance of the Interoperability Framework for Rail and Intermodal Mobility) [114]** project is to fill in a specific role within the Shift2Rail Innovation Programme related to Passenger Services (IP4) by identifying and removing obstacles which could prevent the successful deployment of a fundamental technology (the Interoperability Framework), developed in other projects.

Fulfilment of barrier:

Implementation of algorithmic governance and transport integration can be found as a major subject in presented projects giving answers and predictions for future time horizons in terms of rail transportation.

6.2.1.4 Water transport – autonomous ferry

Barrier: Implementation of regulations and operational standards for near real-time water traffic management (covering sustainability issues, nowcasted demand for cruises, as well as emergency, military or other public service operations prioritizing).

Enabling projects:

- **AutoFerry, by NTNU [50]** – Among other objectives of the project, it aims at development of on-demand ferry.
- **Marine Tractor Beam, by VTT SENSEWAY [54]** – A platform that provides situational awareness as a service for vessels by digitalizing the real world and enabling the enhanced traffic monitoring and control for ports and other shore-based operators.

Fulfilment of barrier:

The barrier is well addressed by these projects. They address the issues of water traffic management and analysis of the demand for cruises in nearly real time providing the safe, uncongested and comfortable travelling.

Barrier: Standards and regulations concerning AI procedures in case of appearing unintended, unexpected situation (covering risk mitigation and occurrence severity minimization/optimization).

Enabling projects:

- **Shone [115]** – A startup company that utilizes the artificial intelligence to reduce incident rates, prevent major accidents and increase the ships safety. AI is employed to detect obstacles up to 10nm around the vessel, at day and night and react, providing the crew with the best course of action for every situation.
- **Orca AI [116]**– AI navigation platform that combines sensors and cameras with deep learning algorithms. It is able to locate and track other vessels on the water and take action to avoid collisions.

Fulfilment of barrier:

The projects indirectly address the barrier being the driver for further regulatory actions. They deliver the risk mitigation in case of unintended and dangerous situations at the same time avoiding the upcoming collision by employing artificial intelligence and hardware solutions.

Barrier: Availability of communication technologies providing ability to efficiently communicate all users. Regulations and standards for 5G and beyond.

Enabling project:

- **EfficienSea 2 [117]** – Among other objectives, it focuses on the development of a hybrid communication system for maritime applications including a new standard of wireless data transmission referred to as VDES (VHF Data) Exchange System).

Fulfilment of barrier:

The projects cover the issues of e-communication for maritime applications by improving navigational safety and efficiency and also ships connectivity. The subject of the project may serve father regulatory actions, thereby fulfilling the barrier sufficiently.

Barrier: Implementation of algorithmic governance in order to assure efficient high-level management of air transportation as well as integration with other modes of transport.

Enabling projects:

- **Multimodal Autonomy Framework, by VTT SENSEWAY [118]** – The project creates a base for autonomy or AI development on land, in the air and at sea by providing access to reusable components from sensors to software and from system architectures to AI models.
- **Navi-Planner [119]** – An AI platform that uses machine learning to optimize voyage planning. Safe navigation routes are automatically created according to the latest charts and environmental information available. It records any near-misses and other incidents that occur

during voyages. The system will also be able to adjust routes and speeds to ensure arrivals take place on schedule.

- **Digital twin, by DNV GL [120]** – Digital twins with large amounts of operational data for existing vessels will be of high value when developing and testing methods and algorithms for remotely controlled and autonomous applications.

Fulfilment of barrier:

The barrier is addressed in an excellent way. The presented solutions provide the tools for automated management of vessels in conformance with other transport modes. What is more, utilizing the algorithms, the solutions ensure the cruise path optimization based on environmental conditions. Besides, algorithms within the tools allow for a comprehensive analysis of the vessel throughout the whole lifecycle.

6.2.1.5 Multimodal transport – flexible chassis systems

Barrier: Regulations and operational standards for integration of airports, vertiports or airfield enabling safe and efficient automatic approach, and landing, take-off as well as reconfiguration (including capabilities and limitations).

Enabling projects:

- **Uber Elevate [121]** – This project evaluates the integration and adaptation of urban infrastructure for the purposes of on-demand urban transit with the emergence of new generations eVTOLs that exhibit great efficiency. The project considers integration of vertiports with existing infrastructure for car riding.
- **Multimodal Hub, by Granstudio [122]** – The multimodal hub is a mobility service infrastructure to switch seamlessly between the car and different modes of transport, allowing to make city centers car-free.

Fulfilment of barrier:

These projects sufficiently cover the aspects of different modes of transport integration in terms of shared and interconnected infrastructure for greater efficiency of on-demand urban transit and passengers convenience.

6.2.2 Enablers for technological barriers

6.2.2.1 Air Transport

6.2.2.1.1 Air Transport (SATS, STOL)

Barriers:

- **Development of affordable technologies enabling reduced operational cost without compromising safety.**
- **Affordable safety technologies compensating risk increase resulting from higher weight of unmanned UAM aircraft and people aboard (concerning bird deterrence, aircraft components reliability, wind gust avoidance).**

- **Limitations due to unpredictable atmospheric conditions due to climate change and weather phenomena intensification.**
- **Technologies reducing the noise of passenger aircraft.**
- **Adequate security solutions preventing from vandalism, terrorist attack, etc.**

Enabling projects:

- **Alice, by Eviation [123]** – Alice is designed from the ground up for regional commutes, being electric, the typical noise and vibrations of other aircraft are dramatically decreased.
- **Heaviside, by Kittyhawk [72]** – Heaviside is equipped with a custom aircraft recovery parachute as a supplemental safety system. Through hundreds of test flights, Heaviside continues to prove exceptional handling of single-system faults common-mode failures.
- **Urban Air Mobility (UAM) Market Study [124]** – The report comprehensively covers the issues of UAM deployment, including security and terrorist activities.

Fulfilment of barriers:

The examples of innovative aircrafts meet the assumptions of the barrier by providing the solutions for clean, affordable, quiet, efficient and reliable propulsion systems that contribute to the more accessible and acceptable urban air mobility. New manufacturing technologies assuring lightweight design as well as safety features such as parachute system lead to increased reliability and social acceptance.

6.2.2.1.2 Air Transport - Certification (SATS, STOL, PATS, VTOL)

Barrier: Certification standards for passenger unmanned air vehicles operating over densely populated areas.

Enabling projects:

- **Vahana, by Airbus [125]** – It is an all-electric, single-seat, tilt-wing vehicle demonstrator that is focused on advancing self-piloted, electric vertical take-off and landing (eVTOL) flight.
- **City Airbus [126]** – It is an all-electric, four-seat, multicopter vehicle demonstrator that focuses on advancing remotely piloted electric vertical take-off and landing (eVTOL) flight.

Fulfilment of barrier:

Vahana and City Airbus as unmanned aircraft demonstrators must undergo the certification process. It paves the way for the detailed certification standards that must be developed and cover all the crucial aspects for passenger flights. The barrier is partially fulfilled as the draft of SC-VTOL regulation is already released but misses many necessary details.

6.2.2.1.3 Air Transport - Infrastructure for air transport

Barriers:

- **Standards and certification covering all regulatory and technical aspect of location of small aerodromes within a densely populated city structure (connected, integrated, safe and small in terms of land use). Including regulations for rooftops and designed drone towers for vertical take-off and landings and covering storage of dangerous materials like fuel cells.**

- **Security assurance for small intra-city aerodromes (vertiports as part of transfer infrastructure).**

Enabling project:

- **Urban-Air Port and Hyundai Air Mobility [127]** – It is a partnership to explore the creation of a purpose-built, multi-functional and scalable infrastructure to enable urban transportation systems to move people and cargo by air.

Fulfilment of barrier:

The partnership of Urban-Air Port and Hyundai Air Mobility goals meet the barrier indirectly. By creation of the UAM services, involving the development of the eVTOL aircraft and the infrastructure on the ground, this will be the basis and support for further regulatory actions.

6.2.2.2 Road Transport

Barriers for Personal Transport – Electric car

- **As in 2035 and in addition the following considerations apply:**
- **Limitation of supply of electric energy resulted from increased demand.**
- **Technologies for low cost electric energy production.**

Barriers for Personal Transport – Autonomous Car

- **As in 2035 and in addition the following considerations apply:**
- **Availability of reliable onboard technologies assuring separation from obstacles, pedestrians or other vehicles enabling autonomous drive in mixed environment.**
- **Standards and regulations covering requirements to be imposed on autonomous car and buses in mixed traffic other than addressed by digitalization domain (concerning onboard equipment).**
- **Standards and recommendations for dedicated infrastructure assuring safe operation of autonomous cars and buses (covering road signs, road specification, necessary equipment, bus stops).**
- **Standards and recommendations for operating of autonomous vehicles in mixed environment concerning ethics, definition of safest solution, minimization of risk or accident severity.**

Barriers for Public Transport – Autonomous bus

- **As in 2035 and in addition the following considerations apply:**
- **Availability of reliable onboard technologies assuring separation from obstacles, pedestrians or other vehicles enabling autonomous drive in mixed environment.**
- **Standards and regulations covering requirements to be imposed on autonomous car and buses in mixed traffic other than addressed by digitalization domain (concerning onboard equipment).**

- **Standards and recommendations for dedicated infrastructure assuring safe operation of autonomous cars and buses (covering road signs, road specification, necessary equipment, bus stops).**
- **Standards and recommendations for operating of autonomous vehicles in mixed environment concerning ethics, definition of safest solution, minimization of risk or accident severity.**

Enabling projects:

- **GLOBAL ENERGY TRANSFORMATION [128]** – The report refers to increased use of renewable energy, combined with intensified electrification and gives a roadmap to 2050.
- **The r-evolution of driving: from Connected Vehicles to Coordinated Automated Road Transport (C-ART) [86] –** It emphasizes that some kind of central management may become necessary in order to guarantee that the full system benefits of road transport automation can be reaped. Coordinated automated and connected vehicles (Coordinated Automated Road Transport, C-ART) are investigated in this study as they could contribute to avoid possible negative consequences of road automation and enable a safe low emission mobility.
- **Penetration of Electric Vehicles toward 2050 [129] -** This paper examines possible future penetration of electric vehicles (EVs) toward decarbonization of energy system in Japan by utilizing a bottom-up energy technology mix model which incorporates a high-temporal-resolution power sector.
- **Effect of electromobility on the power system and the integration of RES [130] -** The objective of the study is to better understand the implications related to the increasing share of electric vehicles for the power system. Different electric vehicle charging strategies are evaluated in terms of power system impacts.
- **Autonomous Vehicle Implementation Predictions Implications for Transport Planning [87] -** The report explores issues like: how autonomous (also called self-driving or robotic) vehicles (AVs) will affect future travel, and therefore the need for roads, parking facilities and public transit services, and what public policies can minimize the problems and maximize the benefits of these new technologies.
- **A time of unprecedented change in the transport system [48] -** Based on the analysis of past and current trends, and the likely impacts of new developments under different scenarios, this report identifies ten priority areas for the UK government in terms of future solutions for many modes of transportation in 2040 and beyond time horizon.

Fulfilment of barriers:

Many barriers have been defined for road transport in terms of technology. All of them find answers in enabling projects which give relevant information and specific roadmap for implementation of new technologies and new regulations.

Barriers for Shared Mobility – Electric Autonomous Car:

- **As in 2035 and in addition the following considerations apply:**
- **As for electric autonomous car (the reader is referred to the related paragraph).**

Enabling Projects: as for electric autonomous car (the reader is referred to the related paragraph).

Fulfilment of barriers: as for electric autonomous car (the reader is referred to the related paragraph).

Barriers for Shared Mobility – Micromobility:

- **As in 2035 and in addition the following considerations apply:**
- **Weather and climate phenomena intensification.**

Enabling project:

Living lab e-micromobility – MOBY [131] - Micromobility should be seen as a new mode of transportation, which responds to a widespread demand for multimodal urban transport. This conclusion points to a need for conceptualizing perspectives and possible regulative frameworks, which could enable micromobility to become a significant part of an open-to-public multimodal system.

Fulfilment of barrier:

Provided report is a complex document about micromobility which takes under consideration all demands defined as barriers including details like weather conditions and carrying baggage issues.

6.2.2.3 Rail Transport – Autonomous rail wagon (AGV)

Barriers:

- **New standards and recommendations optimized for high-efficiency autonomous railway management for wagons, cars, locomotives, multiple units, in parallel for both freight and passenger transport.**
- **New standards and recommendations optimized for high-efficiency autonomous railway management for railroad infrastructure.**
- **New standards and recommendations optimized for high-efficiency autonomous railway management passenger dedicated infrastructure**

Enabling projects:.

- **PINTA3 [132]** - Next generation of traction systems, including silicon carbide semi-conductor-based tractions systems demonstrations on trains, wheel-motor demonstration on high speed trains, smart maintenance, virtual validation and eco-friendly heating, ventilation, air conditioning and cooling (HVAC) and research on battery and hydrogen powered regional trains.
- **DAYDREAMS [113]** – Moving forward the S2R JU vision, in the integration and use of data and artificial/human trustworthy intelligence together with context-driven HMI for prescriptive Intelligent Asset Management Systems (IAMS) in railway.
- **Landside Airport Accessibility (LAirA) [133]** – The project is aimed to reduce the environmental impact of transport activities to and from an airport by changing the mobility behaviour millions of airport passengers and employees across seven airports in Central Europe (Budapest, Dubrovnik, Milan, Poznan, Stuttgart, Vienna and Warsaw). To achieve this goal, LAirA project brought together local and regional authorities, as well as airports, to build their capacity and facilitate joint planning and implementation of low carbon mobility solutions.
- **Shift2Rail IP2 [92]** - The project addresses the adaptation of the European Rail Traffic Management System (ERTMS) for automated train controlling capacity – and even bring in automated mainline freight trains by 2030. The European Rail Traffic Management System

(ERTMS) is a single European signaling and speed control system that ensures interoperability of the national railway systems, reducing the purchasing and maintenance costs of the signaling systems as well as increasing the speed of trains, the capacity of infrastructure and the level of safety in rail transport. A key challenge for Shift2Rail IP2 is to enhance the advanced traffic management and control systems without impacting the ERTMS core, and where appropriate and necessary, to provide backwards compatibility to protect investments both in mainline and urban railways.

- **GEARBODIES [134]** – The project aims to improve the efficiency of rolling stock maintenance in close collaboration with the ongoing PIVOT2 project. The success of the European rail system to foster the modal shift towards rail requires cost-efficient and reliable long-lasting trains, and this project will contribute to its achievement.
- **PLASA-2 [135] -** Smart Planning and Virtual Certification aims to develop a new integrated smart planning simulation approach that can analyze entire networks. It also aims to explore virtual certification to reduce the duration and cost of obtaining authorization for new trains. The project's concept will make strategic capacity planning possible to support investment and reinvestment decisions in the railway sector.
- **RECET4Rail [136]** – The project focuses on the following new technologies for the traction drive sub-system: development of design approaches, end-to-end conception time evaluation and feasibility/performance study of 3D printing technologies for new traction components use cases.
- **TAURO's (Technologies for Autonomous Rail Operation) [137]** - The high-level objective of the project is to identify, analyse and finally propose suitable founding technologies for the future European automated and autonomous rail transport, to be further developed, certified and deployed through the activities planned for the next Shift2Rail programme.

Fulfilment of barriers:

Projects listed as enablers in terms of technology for autonomous rail wagon fully cover all aspects related to defined barriers bringing relevant knowledge of possible scenarios to be deployed in the future.

6.2.2.4 Water Transport – Autonomous ferry

Barriers:

- **Efficiency, safety and reliability of fuel cells and the goal of chasing fossil fuel energy density.**
- **Standards and recommendations concerning safe operation in changing mixed traffic conditions (e.g. risk mitigation, emergency situation management, recovery).**

Enabling projects:

- **Norled, hydrogen-powered car ferry ([100],[138])** – It is a ferry that utilizes hydrogen in a liquid state to be fed into the fuel cells to generate electricity.

- **MUNIN, D5.2: Process map for autonomous Navigation [99]** – This deliverable of the project indicates the navigational standards that refer to traffic management systems, collision avoidance that minimize the maritime incidents likelihood.

Fulfilment of barriers:

The barrier is well addressed by the projects. They aim at providing both the high powertrain efficiency affecting the enhanced range capabilities of the vessel as well as the standards and procedures for safe cruising.

6.2.2.5 Multimodal Transport – Flexible chassis system

Barriers:

- **Development of propulsion systems as well as a set of numerous dedicated technologies (e.g. rotors platform detachment systems).**
- **Development of adequate technical standards and regulations concerning unique components of the flexible chassis system.**

Enabling project:

Pop.Up Next [139] – It addresses an electric, fully automatic concept for horizontal and vertical mobility. In the far future this vehicle could transport people in cities quickly and conveniently on the road and in the air, at the same time solving traffic problems.

Fulfilment of barriers:

The project addresses the barrier indirectly by delivering innovative platform for multimodal transportation. The further regulatory actions may evolve to meet the technological advancements.

7 High level intermodal transport system architecture

This section of the document describes, at high-level, the elements of the system and their relationships according to envisaged intermodal transport system architecture, by distinguishing the three time horizons considered in the project, i.e. 2025, 2035, 2050.

Moreover, existing/future infrastructures and technological enablers are taken into consideration; interfaces and IT components are also outlined, even if they are specifically addressed in WP4.

Given the "exploratory research" nature of the project, the proposed ConOps attempts to identify very futuristic solutions without obviously dealing with a design work.

In particular, a crucial role in achieving the ambitious goal of enabling door-to-door connectivity, in up to 4 hours, between any location in Europe, will be played by the "intelligence" included in the algorithms that will manage the intermodal system.

In this context, the elements must be considered in a broad sense because, for example, services must also be included. Indeed, the means and infrastructures are enhanced by new technologies but it is also obvious that the functioning of the system is strongly linked to the quality of services.

Furthermore, since the development of aeronautical/vertical technologies supporting Multimodal Mobility (MM) is very critical for a correct implementation of intermodal transport, by considering the time horizons identified, the related technological roadmap has been drawn up in the following Table 4.

The elements of the system (means, infrastructures, services and interfaces) are detailed in the following paragraphs:

1 – Means (vehicles)

The following list includes the transport technologies (aircraft, vehicles, etc.) that will support the MM. Specifically, aeronautical, road, rail and water technologies are considered, whose detailed description is reported in the X-TEAM D2D project deliverable D2.1 "Future Reference Scenarios and Barriers" [6].

<u>Aeronautical/vertical transport technologies:</u>

- Small Aircraft Transportation System (SATS);
- Short Take-Off and Landing (STOL);
- Vertical Take-Off and Landing (VTOL);
- Personal Air Transportation System (PATS).

<u>Road transport technologies:</u>

- Electric cars;
- Autonomous vehicles;

- Autonomous (electric) buses;
- Transit elevated buses;
- Shared electric autonomous cars;
- Shared (electric) micro-mobility vehicles.

Rail, water and multimodal transport technologies:

- Autonomous rail wagons;
- Autonomous ferries;
- Flexible chassis systems (multifunctional vehicles).

Including the role of ATM in the multimodal transport, the architecture of the intermodal system (such as indicated in the Use Cases described in Deliverable 2.1 [6]) is "ATM-centred". Therefore, the air transport mode (in particular, the Urban Air Mobility) plays a central role and, for this reason, the following technology roadmap is shown in the Table 4 below.

Table 4 – Roadmap for aeronautical/vertical technologies

Technology	2020	2025	2035	2050
SATS				
STOL				
VTOL				
PATS				

Here below relevant aspects for the definition of the high-level intermodal transport system architecture are outlined about the aeronautical/vertical technologies indicated in the previous table, which have been examined more in details in [6]:

- For what concerns the SATS technology, it is almost already available, but other advances will still have to be achieved in an environment in which safety assurance and affordability are key and often conflicting constraints.
- With reference to STOL technology, it is partially available, since while aircraft development is now mature, short runways are still not very widespread in urban areas. Consequently, its potential cannot be fully exploited yet.
- VTOL technology, then, perhaps the most important element for Urban Air Mobility, is even less available, since there are few ready-made aircraft, and the biggest challenge will be building and managing the dedicated infrastructure.
- PATS technology presents the same problems mentioned in the previous item, but very more stringent regulatory aspects will have to be addressed.

2 - Infrastructures

For a system as complex and distributed over very large spaces as intermodal transport, the infrastructures represent the backbone. Furthermore, they have a huge impact on investments, management costs, environmental impact, urban and territorial planning. Consequently, it is necessary to consider as many ideas as possible in order to create an efficient, sustainable and green system.

For example, it is possible to consider extending the use of superfast charging stations (currently with maximum power of 350 kW) already designed for electric cars to eVTOL aircraft, key elements of Urban Air Mobility. Similarly, Vehicle-to-Grid (V2G) technology could also be used which connects electric vehicles to the energy grid to exploit batteries as stabilizers, accumulating energy when it is produced in excess and giving it away at times of peak consumption, allowing a reduction in CO2 emissions and a savings on operating costs.

Below, considerations inherent to existing/future infrastructures that could have great impact on Multimodal Mobility are listed.

- Integrated dynamic capacity: ensuring that capacity across modes is integrated and responsive to real-time demand and changes.
- Car-aircraft integrated structures dedicated to increasing electrification.
- Infrastructures dedicated to Urban Air Mobility: vertiport, specific accesses, dedicated services and high integration.
- Luggage handling infrastructure: operational and security alignment on luggage handling across air, rail and train systems is important to enable seamless, intermodal and traceable solutions.
- Accessibility and comfort: access to several modes at airports and design for the passenger diversity.
- Urban air-rail-train mobility at multimodal hubs.
- Environment impact: decrease of unnecessary trips and noise at airport.
- Green travel: transparency, eco-friendly modes through the D2D chain.
- Parking and airports-city centre links.

3 - Services

Listed below are possible services that could have an important impact on MM and could be the keystone for a fruitful implementation of the intermodal system. Indeed, the quality of the services will have a huge weight on the achievement of the expected objectives.

- Multimodal trip pack creation and insurance.
- Establishing prices by optimizing the travel costs of the different transport modes.
- Ticketing interoperability (flexible in case of disruption) and integrated tickets.
- Single ticketing: single booking tool, one stop shops (MaaS tickets).
- Fluid travel info and facilities across modes on multimodal trip, delivering better confidence for all stakeholder types.
- Passenger diversity (disabled, languages, infrequent travellers).
- Resilience to disruption for passenger and flexibility to recover in buffer times.
- Disruption services, e.g. enabling passengers to re-book and re-plan during disruption.
- Personalisation of travel: inclusion, personal preferences, peace of mind, safety.
- New Mobility Services (NMS), e.g. car-sharing, ride-hailing, bike-sharing, e-scooters, e-bikes.

4 - Interfaces and IT components

Intermodal system interfaces and IT components that could have a major impact on Multimodal Mobility are listed below. In particular, coordination, management algorithms, accurate and real time information will play a decisive role in the correct implementation of the intermodal system.

- Coordination of actors across all modes (air-rail-train transport) through collaborative processing.
- D2D development requests data availability, information/data sharing and adapted policies.
- Optimized or AI-based intermodal system management algorithms.
- Multimodal info to passenger in planning and execution.
- Intermodal transfer accessibility and efficiency by improving connection times and reliability at cross-modal interfaces.
- Real time, user-friendly, accessible and accurate information before and during the trip.
- Transfer time, development of intermodal hubs between all modes of transport and information in case of disruption.

In this section, therefore, the architecture of the Intermodal System will also be outlined. In particular, the focus will be on how intermodal travel is structured, by using the Use Cases described in the D2.1 document [6] as a starting point to define the needed system architecture to allow implementation of the defined Use Cases.

7.1 The 2025 timeframe

In this subsection, elements, infrastructures and interfaces of the intermodal system will be described by considering only the 2025 time horizon. In particular, all the elements above identified will be considered at their almost current state of development as components of the 2025 baseline intermodal transport system architecture.

7.1.1 Architecture outline

Considering the 2025 time horizon, the structure of Intermodal travel is outlined adopting the technologies, infrastructures and services currently available.

In particular, very realistic Use Cases will be considered, considering existing infrastructures and means already available now or in the immediate future (up to 2025). In fact, it is plausible to classify the three main elements of the Intermodal Transport System, based on the speed with which they will evolve, in the following (increasing) order: infrastructures, means, services.

Consequently, at present, while services (being the most easily remodelled) certainly do not constitute a bottleneck, infrastructures are still in an embryonic phase. Therefore, in outlining the architecture of intermodal travel, in this period, the focus will be mainly on the means (vehicles) and on the technologies on which they are based.

In particular, based on the Use Cases defined in section 5.5.1 of the D2.1 document [6], here in the following the steps that schematize this potential intermodal journey are identified:

- Traveller starts her/his trip at home: multimodal journey has to be planned in advance and to be managed by the traveller themselves. Planning can be done with the use of online services available. There is the possibility to buy tickets in advance, to proceed check-in at least the day before flight, and remote ticket validation systems are available. Flight is booked via travel agency, app or internet in advance.
- Using the combination of bus and train to reach the regional airport, because change from one mode to the other is comfortable (ticket purchased via mobile app/online).
- Arrival at the regional airport (passenger checked online the day before): need to walk. Time spent to reach the gate is significant.
- Flight with an aircraft (digital ticket purchased online).
- Arrival at hub airport: there is no direct access to e-bikes or e-scooters sharing system. Also getting car-sharing or rental cars services requires longer walk distance.
- Traveller takes rental car from airport or uses the combination bus and train of the public service.
- Traveller arrives at destination.

The Figure 4 illustrates the selection of possible modes of transport in this timeframe (2025). The Intermodal System Architecture is described thinking only of the outward journey because the return is, so to speak, the reverse image. The two main nodes are the regional airport and the hub airport.

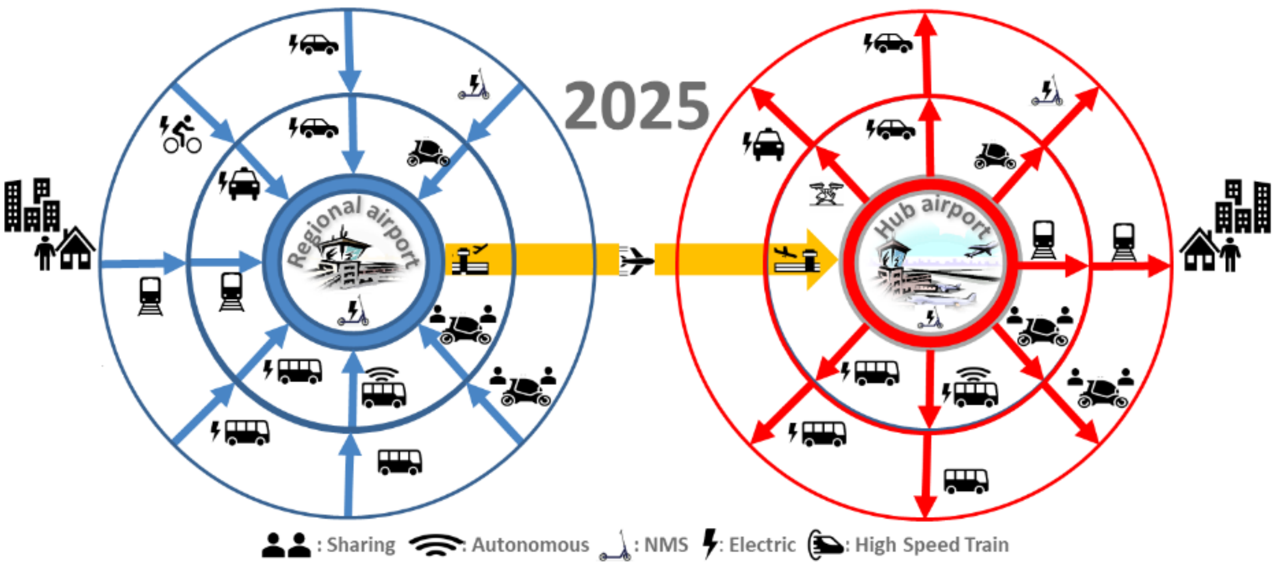

Figure 4 – Intermodal System Architecture in 2025 timeframe

7.1.2 Main elements of the intermodal system

In the 2025 timeframe, the trend of convincing people to use collective modes of transport instead of private cars through the application of complex wide-range metropolitan solutions increasing their attractiveness (for example, closing city centres for non-electric cars, decreasing the travel speed in urban area, modernization of the mass transport) will be present.

Commercial air transport connections will be available only on the most crowded destinations (mostly touristic traffic/charters oriented). In addition, there will be also locally available connections executed by small aircraft in scheduled way (between islands or to remote sparsely populated destinations).

New Mobility Services (NMS), i.e. car-sharing, ride-hailing, bike-sharing, e-scooters, e-bikes, will be gaining users' interests earning significant share in the transport system.

Moreover, the technological roadmap shown in Table 4 indicates the state of development of the aeronautical technologies supporting the Intermodal Transport System for the 2025-time horizon.

To allow achieving in the future an environment that integrates UAM solutions in the context of the Intermodal Transport System, it will be very important already at present:

- to monitor and safeguard the effective use of existing urban infrastructure to better serve intermodal transportation development;
- to design and certify vertipads (necessary for vehicle take-off and landing) that integrate positively with existing urban infrastructure.

Furthermore, the following considerations apply to airports:

- Connection of hub airports with one or two regional airports is implemented (point-to-point connections executed by Low-Cost Carrier (LCC) airlines).
- Hub airports are connected with the city by numerous modes (trains, bus, taxi).
- From the hub airport there is no direct access to e-bikes or e-scooters sharing system.
- Also getting car-sharing services requires longer trips to walk (due to pressure on cost, contrary to rental cars).
- Regional airports provide access to one or maximum two public transport services (train, bus). It is easier than in hub airport to rent a car or use NMS, including e-scooters and e-bikes (depending on the airport location).

7.2 The 2035 timeframe

In this subsection, elements, infrastructures and interfaces of the intermodal system will be described by considering only the 2035-time horizon. In particular, all the elements identified above must be considered with a greater degree of innovation, given the additional decade available for technological development.

7.2.1 Architecture outline

Considering the 2035-time horizon, the structure of the intermodal travel is outlined by estimating the updating that technologies, infrastructures and services will achieve over a decade.

Therefore, in outlining the architecture of Intermodal Transport System, for this period, the focus will be on both means (vehicles) and infrastructures. As a result, the passenger-trajectories will benefit from infrastructures better connected.

In particular, the outline of the structure of Intermodal travel for the 2035 timeframe will be based on the related Use Cases defined in section 5.5.2 of the D2.1 document [6]. Below are reported the steps that schematize this potential intermodal journey:

- The traveller starts the journey at home: exchange of information between ATM and surface modes together with access and communication with user's portable device allows for providing traveller with all data concerning her/his multimodal journey in advance (at least a day before the start of travel). The traveller will be provided with all available alternatives allowing him to react in time (in respect to her/his requirements, e.g. related with disabilities). Privately generated data will be available for service providers and daily demand forecasts will become possible making transport system more efficient and sustainable. This development means for planning that in case of unexpected complications, no buffer is needed at the beginning of the journey to reach the airport in time.
- Traveller has got the possibility to modify the journey a day before travel (selecting other modes according to his preferences). Traveller will be offered to purchase one single ticket for entire journey with access rights to particular change nodes. Check-in is done automatically at the start of the journey, at the first hub. Due to technology development, the users' focus will shift to personal needs as well as the impact on the environment.
- Walking to e-scooter/e-bike sharing depot and using such a mean to reach e-VTOL platform (covered by a single ticket for the entire journey). Not completed digitalization of the Intermodal System will prevents including all available transport modes.
- Taking e-VTOL flight to the regional airport (single ticket online using mobile app).
- Arrival at the regional airport (passenger automatically checked in the first node): use of e-scooter. Time spent to reach the gate will be slightly reduced.
- Flight by a short-range aircraft.
- Arrival at hub airport: there is no direct access to e-bikes and e-scooters sharing system. Electric taxis are partially replaced by electric car-sharing and easier accessed from the airport terminal.
- Traveller takes electric car-sharing from airport (included in the single ticket booked in advance) or uses various combinations of public transport.
- Traveller arrives at destination.

The Figure 5 illustrates the selection of possible modes of transport in this timeframe. As already pointed out, the Intermodal System Architecture is described thinking only of the outward journey. The two main nodes are the regional airport and the hub airport.

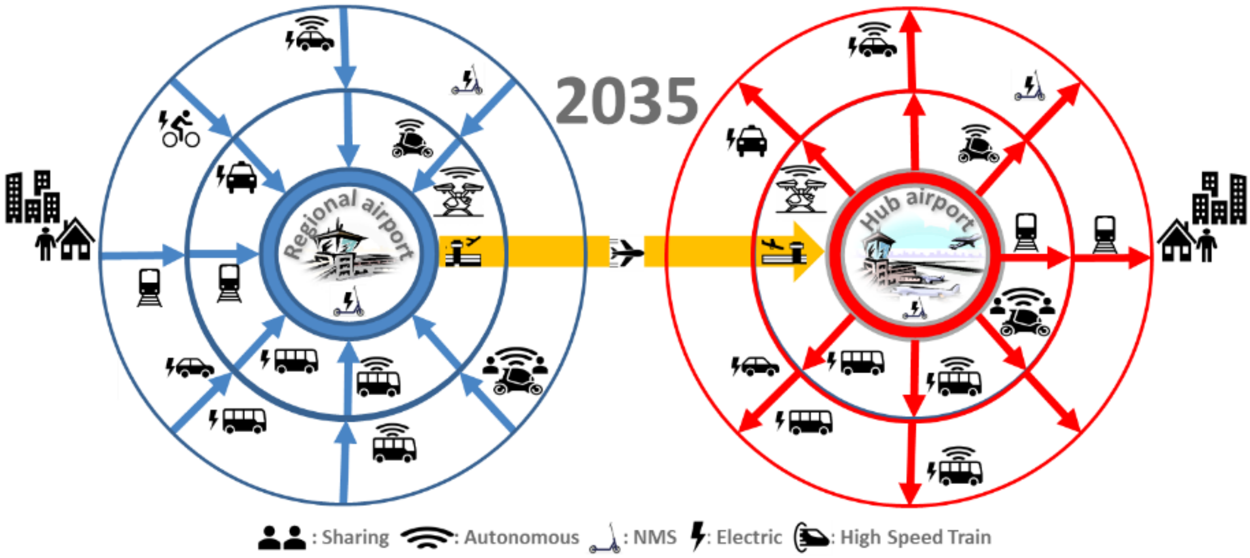

Figure 5 – Intermodal System Architecture in 2035 timeframe

7.2.2 Main elements of the intermodal system

The technological roadmap shown in Table 4 reports the expected development of the aeronautical/vertical technologies supporting the intermodal transport system for the 2035 time horizon.

Over the next ten to fifteen years, efforts made in the infrastructure sector will have to consider an ever-greater optimization. In particular, it will be very important to:

- support a broader urban planning capability that relies on extensive collaboration with local ecosystems that build and live in the urban context;
- create solutions that adhere to the principles of *Functional Compactness*, which aims to enhance the value of transport infrastructure and adapt its use for future mobility evolutions.

Together with progress in the process of circular economy paradigm implementation in EU, a bigger and more complex transport system will be achieved which will be more sustainable as well. More people will walk, use bicycles and other compact-size means of personal transportation like e-scooters. Traffic by cars will be inhibited by introduction of car-free zones in many cities. Due to technology development, the users' focus will be on personal needs as well as impact on environment.

Consequently, the following assumptions can be made:

- Several percentages of cars available on roads will be electric. Driving performances will be highly automated. In urban areas, the car sharing model will be dominating. In densely populated areas (city centres, where car traffic will be forbidden or limited), electric micromobility means of transport will have a significant share (beside public mass means of transport).

- Public means of transport network will be significantly extended to supply for the increased demand offering higher level of accessibility for citizens and reducing the length of first and last legs of multimodal travel.
- Short range airlines connections will remain the air mode of transport with highest potential to impact efficiency of transport system. Connection of hub airports with one or two regional airports (point-to-point connections) will be in place.
- Urban Air Mobility for passenger transport in experimental sites will be available in Europe but without significant impact on mobility in metropolitan areas.
- Hub airport is connected with the city by numerous modes (with collective transport means as train and bus connections dominating here). Electric taxis is partially replaced by electric car-sharing, more popular than in 2025 and easier accessed from the airport terminal. From the hub airport there is no direct access to e-bikes or e-scooters sharing system, due to remote location of the hub airport with relation to the city.
- Regional airports provide access to more than one public transport services. Electric shared cars or NMS, including e-bikes and e-scooters, are commonly used as airport cities develops (depending on location and size of the airport).

7.3 The 2050 timeframe

In this subsection, elements, infrastructures and interfaces of the intermodal system will be described by considering only the 2050 time horizon. In particular, all the elements identified previously must be considered with the highest degree of innovation since this is the most futuristic step under consideration.

7.3.1 Architecture outline

Considering the 2050-time horizon, the structure of the intermodal travel is designed trying to predict the updating that technologies, infrastructures and services will receive over almost thirty years.

Therefore, in outlining the architecture of the intermodal transport system, for this period, it can be assumed that all the planned updates have been implemented, both in terms of means/technologies and infrastructures.

In particular, to outline the structure of intermodal travel for the 2050 timeframe, the use cases defined in section 5.5.3 of the D2.1 document [6] will be used as reference. Below are the steps that schematize this potential intermodal journey:

- Traveller starts at home: he is provided with all data concerning his multimodal journey at least every hour during the journey. He will have possibility to modify his journey even on the day of the journey (selecting other modes according to his preferences). Traveller purchases one single ticket for entire journey with access rights to particular change nodes. The offer will be designed based on smart pricing favoring preferred/prioritized modes of transport (with regards to applied policy like carbon footprint, emissions, sustainability level). Solutions will cover all or almost all publicly available means of transport. Time spent on changing nodes will be reduced thanks to total system approach applied (System of Systems Management). Completed digitalization will allow the traveller to make transport mode more fitted to his individual preferences/needs. Nearby are New Mobility Services (NMS), including e-bikes/e-scooters and an electric autonomous car sharing depot.

- Traveller is using NMS to go to the next UAM port.
- Traveller is using UAM: for the regional range, air travels will be also possible with use of VTOL, multirotor and fixed wing aircraft.
- Arrival at the regional airport (passenger was checked in automatically): use of UAM gives the traveller direct access to regional city airport. Security check and check-in is already done with/during the use of the UAM.
- Traveller is using NMS (for example, e-bikes and e-scooters) or micromobility means of transport at airport: passenger is in nearly no time at gate.
- Flight with zero-emission large aircraft.
- Arrival at hub airport: NMS are commonly used in airport. There is (electric) micromobility means of transport to take the traveller to high-speed rail transport station.
- High-speed rail transport ride: traveller modifies his journey to his preferences (for example, he likes boat tours) and selects a ride with an autonomous ferry service instead of planned surface traffic modes: connected, cooperative, automated mobility (CCAM).
- Arrival at the high-speed rail transport station with easy transfer to water mode system of the destination city. The destination city is divided by large water reservoirs. Traveller can use an autonomous ferry service instead of planned surface traffic modes.
- Arrival at ferry pier: use of micromobility means of transport to the accommodation.
- Traveller arrives at destination.

The Figure 6 illustrates the selection of possible modes of transport in this timeframe. As already highlighted above, the Intermodal System Architecture is described thinking only of the outward journey and here too there are two main nodes, i.e. the regional airport and the hub airport.

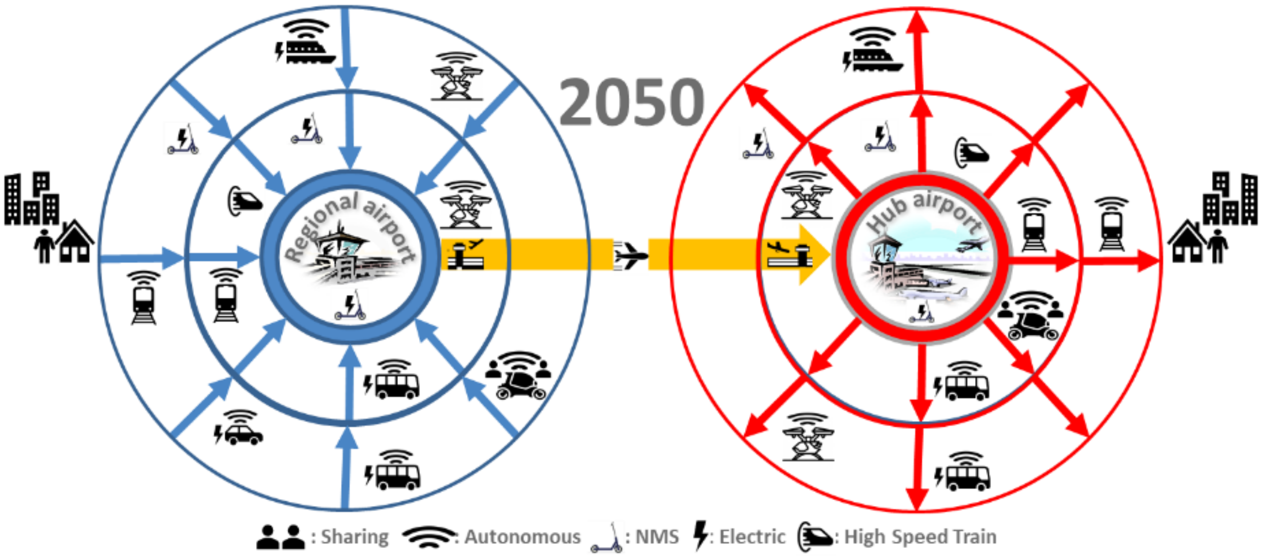

Figure 6 – Intermodal System Architecture in 2050 timeframe

7.3.2 Main elements of the intermodal system

The technological roadmap shown in Table 4 reports the expected development of the aeronautical/vertical technologies supporting the intermodal transport system for the 2050 time horizon.

The role of technology in the cities of the future will be decisive. Automation, electrification, connectivity and telematic services will simplify the relationship between means and users and between means and the surrounding environment, at the same time requiring an innovative rethinking of infrastructures. For example, it will be very important to develop digital infrastructure solutions that help entities and operators to leverage digital technologies in managing future smart cities.

Megacities enhanced by AI and automation will become "smart" and they will serve as the core of global economy. They will deeply cooperate and coordinate using the algorithmic governance. As the dominating part of the energy consumed in the EU will originate from renewable sources, EU transport will reach net-zero emissions level. A policy of walkable cities will cause domination of soft modes, mass transit, NMS and most likely UAM. Intercity traffic will be supplied by high-speed rail transport, CCAM (Connected Cooperative Automated Mobility) and zero-emission large aircraft. This final scenario expects full satisfaction of the travellers' needs.

Consequently, the following assumptions can be made:

- All cars approved on roads will be electric and for the most highly automated and autonomous. In urban areas, car sharing model will be dominating. In densely populated areas (city centres, where car traffic will be forbidden), electric micromobility means of transport will be the only personal transport mode having significant share (beside public mass means of transport).
- Public means of transport network will reach maximum available density to answer increased demand offering highest possible level of accessibility for citizens and reducing the length of first and last legs of multimodal travel.
- Short range airlines connections operated by zero emission aircraft will remain the air mode of transport with highest potential to impact efficiency of transport system. Connecting of hub airports with one or two regional airports (point-to-point connections) will be in place.
- UAM dedicated to passenger transport will be available in Europe offering direct access to densely populated city areas. Regional range air travels will be also possible with use of both new concept aircraft, VTOL, multirotor and fixed wing aircraft depending on appropriate infrastructure availability.
- Hub airport is connected with the city by numerous collective autonomous transport modes, complemented by electric autonomous car-sharing services.
- Regional airports provide access to more than one collective autonomous transport services. Electric shared cars or NMS, including e-bikes and e-scooters, are commonly used as airport cities develops (depending on location and size of the airport).
- In case of favorable conditions (presence of large water reservoir dividing the metropolitan areas), the multimodal journey can also be supported by autonomous ferry services.

8 Concept of Operations of ATM and UTM in the intermodal transport system

In this section, emphasis is placed on some details of the specific roles that ATM and UTM play and how they are performed in the integrated system, according to the three time horizons considered.

It is well known that today's airspace is busier than ever. According to flight aviation data company FlightAware, over 1.2 million people are airborne around the world at any given moment.

Thanks to advanced technologies, new types of aerial vehicles are now being developed and are entering our skies at record speeds (a review of related technologies was carried out in the D2.1 document [6]); these vehicles have new shapes and capabilities/operations at much lower altitudes. All of things that current airspace was not designed to handle: this is a problem that regulatory bodies are addressing in this transitional phase.

Most of the new airplanes that will enter airspace permanently are unmanned: the crucial point is to introduce them safely into the current airspace. A way for them to coexist with each other and with current airspace users, as well as with future users, has not yet been defined. Solutions are currently under consideration, with digitalization and autonomy ready to play a key role in the modernization and safe management of future airspace.

Today, aircraft are safely guided by air traffic controllers who communicate with pilots via the Air Traffic Management system (ATM): this direct, point-to-point, line of sight communication between an operator and an aircraft is the industry standard mode of operation. However, estimates show that the growth in commercial air traffic will eventually outstrip the capacity of a human-centred system and that's only for human-powered flights.

As unmanned and autopilot operations continue to multiply, ATM systems will need to move to a more scalable model: a digital system that can monitor and manage increased activity. This system is called Unmanned Traffic Management (UTM), i.e. a networked collection of services that communicate together based on common rules. Rather than relying on centralized control, UTM frameworks around the world will use the principle of distributed authority, which opens the system to more service providers who can adapt to evolving market and the needs of change.

The whole aeronautical world is working on establishing the basic principles and approaches to UTM frameworks, whose development stages are very similar. In Europe (SESAR) such system is provided by U-Space. Instead, in the United States, NASA is developing a private model known as Unmanned Aircraft Systems Service Suppliers, certified by the Federal Aviation Administration (FAA).

The maturing UAS sector offers many opportunities, but to be fully integrated: unmanned aircraft will need to coexist with manned aircraft and existing aviation systems within finite airspace resources. In doing so, safety must be paramount, and both sectors should be able to cooperate for mutual gain while avoiding undue impacts to existing airspace users or capabilities.

To achieve this objective, the technology used to support UTM systems must not inadvertently degrade ATM systems (e.g. frequency spectrum saturation or jamming). Other issues are important from a societal acceptance perspective such as privacy, security, reliability, environmental protection and the appropriate use of automation.

UAS operators must prove compliance with a minimum set of safety standards and be operationally and legally accountable if routine operations are to be accepted by the public. Each of these issues depends on the harmonization of risk and performance-based regulations and oversight, and should include consideration of emerging technological solutions.

UTM systems are therefore envisaged to be interoperable and consistent with existing ATM systems in order to facilitate safe, efficient and scalable operations. Although system-level requirements for UTM systems have not yet been developed, core principles can be established to guide their development. There are also numerous principles in the current ATM system that are applicable to UTM services. The following principles should be considered [140]:

- Oversight of the service provision, either UTM or ATM, is the responsibility of the regulator.
- Existing policies for aircraft prioritization, such as aircraft emergencies and support to public safety operations, should be applicable, and practices unique to UTM should be compatible with such policies.
- Access to the airspace should remain equitable provided that each aircraft is capable of complying with the appropriate conditions, regulations, equipage/performance requirements and processes defined for the specific airspace in which UTM operations are proposed.
- The UAS operator and/or the remote pilot should be qualified to perform any applicable normal and contingency operating procedures based on the specific class of airspace in which operations are conducted and the UTM services being provided.
- To meet their security and safety oversight obligations, authorities should have unrestricted, on-demand access to UAS operators, remote pilots and the position, velocity, planned trajectory and performance capabilities of each unmanned aircraft being managed by the UTM system.
- In order to achieve an effective UTM capability, the creation, adoption and maintenance of safety culture among the UTM community is essential.
- The free and open reporting of accidents and incidents should be facilitated for all stakeholders.

Where a State is considering the issuance of an operational approval for a UTM system, it must assess numerous factors, including, inter alia, the following safety-significant factors:

- types of unmanned aircraft and their performance characteristics (including navigation capabilities and performance);
- adequacy and complexity of the existing airspace structure;
- spectrum availability and suitability;
- nature of the operation;
- type and density of existing and anticipated traffic (unmanned and manned);
- operational capacity of the UTM system including any airspace constraints;
- levels of and extent of automation capabilities in the UTM system and in the UAS;
- regulatory structure;
- meteorological considerations;
- the requirement for all unmanned aircraft in the UTM airspace volume to be cooperative;
- detection/separation of non-cooperative unmanned aircraft;
- management of aeronautical information service and aeronautical data;

- geographic information systems (GIS) data and additional geospatial data applicable to the UTM airspace.

In the scope of the X-TEAM D2D project, what is of interest is not only when these technologies are ready to be implemented, but also and in particular it is of interest the way and timescale they will be integrated in a context aimed at an intermodal journey, guaranteeing, in the most transparent way possible to the passenger, a journey using the different technologies between air, sea and land.

For this purpose, it is necessary to consider some aspects. In fact, there are 5 key aspects to this integration pertaining to the physical side, the networks, fares, information, and the institutions [141]:

- **Physical integration**. The stations where users can change means of transport should be designed and sited with ease of access in mind.
- **Network integration**. The routes and schedules of each mode of transport should be designed such that they complement and are linked to the other modes in the system.
- **Rate integration**. The fare system or payment method (electronic cards) should be unified; alternatively, users who use different modes during their trips should have special fares.
- **Information integration**. The information of the entire system should be standardised by means of signage which is complete, useful and easy to look-up and understand.
- **Institutional integration**. The different operators and agencies involved in the system should cooperate and coordinate their actions.

The key aspects that have been identified are necessary to understand how the ATM and UTM system behave in an intermodal journey, and how each single aspect evolves with technological progress and regulatory updating over the three time horizons.

In the following three sections, in which the three time horizons under examination are analysed in detail, a score is assigned for each key aspect. In this way, it is immediate to understand for each time horizon the role of ATM and UTM systems and how they evolve over time, to adapt to an intermodal journey in the most efficient and transparent way possible for passengers.

8.1 The 2025 timeframe

As regards the first-time horizon in question, from the analysis of the scenarios carried out in the D2.1 document [6], it emerged that the intention is aimed to have a passenger-centric air transport system integrated with other modes of transport, with the aim of bringing travellers door-to-door in a predictable and efficient manner.

Unfortunately, up to now ATM operations have not had a passenger-oriented development, also because performance objectives did not consider the consequences on passengers. Furthermore, research in this area had limited availability of behavioural data.

Differently, today the pervasive penetration of smart devices in the daily life makes them available to multiple information. Therefore, in the immediate future there is still a lack of adequate tools for the exchange and use of data between the various transports available, which is indispensable in an intermodal trip. Adding the complexity of the network, it does not allow the desired reaction in case of disruption.

This means that from the passenger's point of view, the management of intermodal travel is self-managed, supported by the different applications through their mobile device, gathering data provided by different operators. Thus, the same traveller is the manager of his multimodal journey in case of disruption. Transport process efficiency depends on passenger's ability in managing the journey.

Although some technologies are already mature, it is not possible to see them already implemented, because it is well known that the aviation, including ATM, has a long history during which a high level of safety has been developed and is maintained. A notable characteristic of ATM is that it functions with a well-established and proven safety management system, however its procedures and structures may not allow for quick developments and implementations. By contrast, UTM is innovative and fast, but its level of safety and robustness has not been defined and validated. Accordingly, a high degree of complexity emerges from efforts to integrate these two systems and this is an epochal change for ATM that will be highly impacted from the introduction of the UTM into the airspace.

The establishment of boundaries has not only operational and technical elements, but also legal elements. As UTM is implemented, the fact that the airspace will be shared between manned aircraft and unmanned aircraft creates a need to identify and confirm the roles of UTM and ATM related to airspace and traffic management responsibilities and functions.

The interoperability is a key requirement for UTM-ATM interface. In fact, there is a complex gap between responsibilities of UTM and ATM. The gap has materialized from the fact that the process for designation of UTM service suppliers, their certification, and how they should demonstrate a minimum level of safety and quality of service has not been defined. On the other hand, established Air Navigation Service Providers (ANSPs) are regulated and follow well established procedures.

Besides the gaps which are complicating the establishment of UTM-ATM boundaries, it is hard to achieve the development of UTM in isolation from the existing ATM system and its services. Some of the UTM services have similarities with ATM services. Therefore, coordination with ATM is vital. Other UTM services are complementary to ATM as services are expanded to airspace users in volumes of airspace where ANSPs currently provide limited or no services. Although it is likely that these services will need to interact, there must be no overlap of conflicting or incompatible services or areas of responsibility. As a consequence, UTM services may, in fact, be shared between UTM and ATM.

Because unmanned aircraft have the capabilities for operating in all types of airspace and at all flight levels, it is possible to have scenarios where manned aircraft and unmanned aircraft will be required to cross the boundary between UTM and ATM, whereas in other situations they will only operate in close proximity to that boundary. In both scenarios, an aircraft being managed by one system (UTM or ATM) may be at increased risk of becoming a hazard to aircraft being managed by the other system.

This period will kick-off the implementation of the new standards. In particular, the implementation of the first U-Space services will happen but what can be expected is, of course, that the ATM will still be the master, whose update will be under development, with at most some improvements aimed mainly at increasing the level of automation.

In this timeframe it will be experienced the transition from the current architecture built in three layers, which poorly adapts to the new intermodal scenario, due to the poor scalability of fixed routes, whose services have a low level of automation and information sharing. The future architecture is expected to be divided into five layers:

- higher airspace operations,
- network operations,
- air traffic services,
- data and application services U-space operations,
- infrastructure.

These levels will not yet be fully operational for this period but it can be assumed that standards and rules will be in place to support airspace reconfiguration, capacity-on-demand, and drone services. In particular, it is expected at least the implementation of the first two levels of U-space services. In fact, for this period the UTM will still be experimental and the object of research, therefore only some tests of unmanned aircraft and some UTM implementations in this sense will happen.

In light of the above, for a passenger who is preparing to embark on an intermodal journey at this time, the aerial technologies with which they are expected to travel will still be the conservative ones, i.e. those managed by the ATM.

Therefore, in summary the main aspects characterizing ATM and UTM Concept of Operations for the 2025 timeframe are:

ATM sector

- ATM still the master;
- update under development;
- level of automation increasing.

UTM sector

- UTM still experimental and object of research;
- at least first levels of U-Space Services implemented.

Therefore, as summarized in Figure 7, where the workload distribution between the two systems is indicated, for this time horizon the workload will be exclusively on the ATM side.

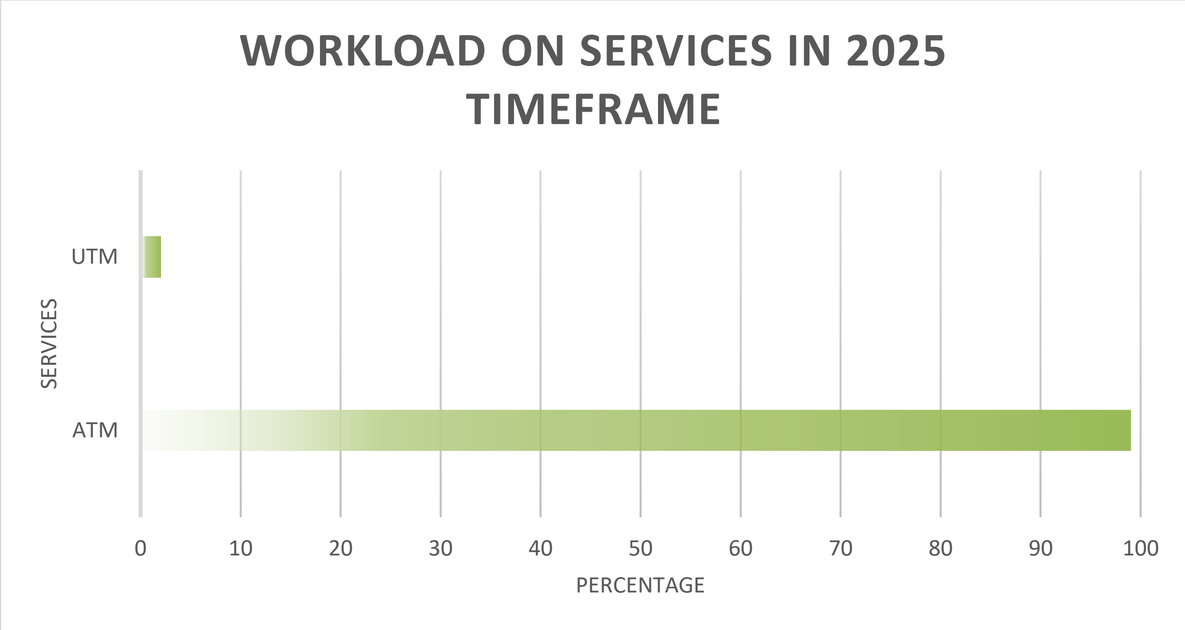

Figure 7 – Workload of ATM and UTM services in 2025 timeframe

As previously mentioned, by analysing the key aspects identified it is possible to understand where there have been advances and where, instead, there is still work to be done, in order to be able to better integrate the two systems in an intermodal journey. In particular, in Table 5 it is emphasized that:

- On the ATM side, there is work to be done especially in communications, both in terms of network and information sharing (in particular, the tickets management for the entire journey which involves different technologies and also various services providers).
- On the UTM side, there is still work to be done in all aspects. Unmanned traffic must be managed and regulated. Stakeholders need to solve the safety, security and privacy issues of drones.

Table 5 – ATM and UTM integration key aspects scores in 2025 timeframe

	ATM	UTM
Physical integration	★★★☆☆	★☆☆☆☆
Network integration	★★☆☆☆	★☆☆☆☆
Rate integration	★☆☆☆☆	★☆☆☆☆
Information integration	★★☆☆☆	★☆☆☆☆
Institutional integration	★★★☆☆	★★☆☆☆

8.2 The 2035 timeframe

This period is what we could define in some way as the one that marks the transition between the old model and the new one, both from the technological and the regulatory point of view. For this era, it is expected to have the first integrated UAS in all classes of airspace.

In Europe, the new ATM data service provision model will be available. With the support of new certified technologies and standards, a more resilient ATM model will be implemented. Fundamental for this purpose will be the support of ATM Data Services Providers (ADSP).

The terrestrial component of air-to-ground communication will require high bandwidth. The new architecture will allow the sharing of resources across the network enabling a more scalable and resilient service delivery to all airspace users. The network, now evolved to the state of the art, will operate at its best performance.

Thus, this timeframe will be the middle of the U-Space testing phase and advanced U-space services (U3) will be operational across Europe.

Unlike the previous time horizon examined, a passenger who is preparing for an intermodal journey in 2035 can also use the technologies provided by the UTM system for the aerial part of the journey. In fact, as indicated in Figure 8, even if the most part of the workload remains on the ATM side, the first UTM services will be ready and therefore it will be possible to use them.

Therefore, in summary the main aspects characterizing ATM and UTM Concept of Operations for the 2035 timeframe are:

ATM sector

- ATM upgraded to more resilient model;
- ATM data services providers fully operational;
- high bandwidth connection between air to ground.

UTM sector

- integration of UAS in all classes of air-space;
- advanced U-Space services ready.

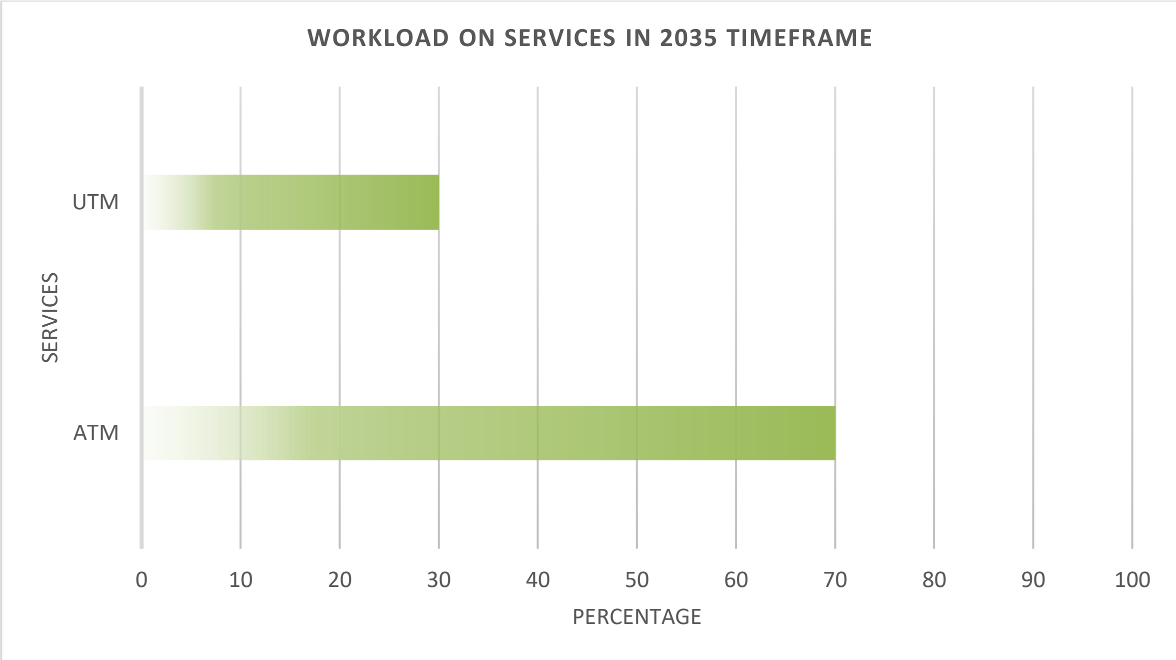

Figure 8 – Workload of ATM and UTM services in 2035 timeframe

As a natural consequence of the above, there will be also an improvement in performance with respect to the key aspects identified. Regarding the UTM system, an increase in the score will be observed, as it can be seen from the summary in Table 6, characterized by the following results:

- on the ATM side, the new architecture will allow the sharing of resources across the network enabling a more scalable model to all airspace users;
- on the UTM side, it will be in progress the U-Space testing phase.

Table 6 – ATM and UTM integration key aspects scores in 2035 timeframe

	ATM	UTM
Physical integration	★★★★☆	★★★☆☆
Network integration	★★★☆☆	★★★☆☆
Rate integration	★★★☆☆	★★★★☆
Information integration	★★★★☆	★★★☆☆
Institutional integration	★★★☆☆	★★★☆☆

8.3 The 2050 timeframe

For this period, a fully scalable and highly automated ATM system, which will lead to a level of security above current levels, will be available. Moreover, service-oriented and passenger-centric ATM, hyper connectivity for high automation and all-weather operations will be available.

U-space full services (U4) will be available. Services that provide integrated interfaces will be activated with manned aviation, supporting the full operational capacity of U-space with a very high level of automation, connectivity and digitization.

Furthermore, the Trajectory Based Operations (TBO) concept will enhance strategic planning of aircraft flows to reduce capacity-to-demand imbalances in the airspace system and will provide tools to ATM to help expedite aircraft movement between origin and destination.

Therefore, through improved strategic planning and management of traffic flows, these will enable modification of the flight's planned and actual trajectory, before or during flight, based on accurate and full integration of information to create a synchronized view of flight data by all actors involved.

The scenario that looks forward to 2050 for the intermodal travel is characterized by a complete offer both as regards ATM and UTM, in terms of integration of technologies and services in the multimodal journey, since the improvements that were missing before this timeframe will be implemented.

Therefore, in summary the main aspects characterizing ATM and UTM Concept of Operations for the 2050 timeframe are:

ATM sector

- ATM highly automated;
- services oriented ATM model;
- passenger-centric ATM model;
- hyper connectivity.

UTM sector

- high level of connectivity and digitization;
- all automated features;
- U-space full services available.

By 2050, thanks also to the experience gained in the design and construction of ATM systems, also solutions for UTM systems will be fully available, relying on new technologies and a high level of automation, to efficiently and safely manage the growing use of unmanned aircraft in door-to-door travel applications.

Thus, at this timeframe, ATM and UTM services will be fully operational in an intermodal journey and they will have the same workload, as shown in Figure 9.

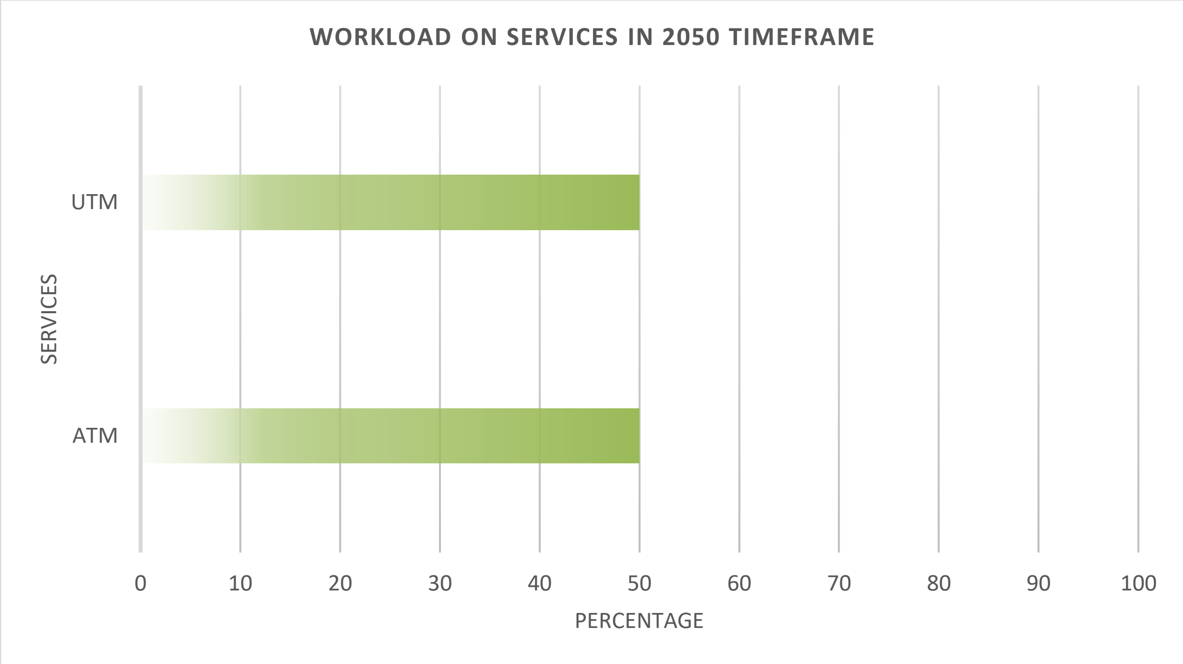

Figure 9 – Workload of ATM and UTM services in 2050 timeframe

Obviously also, as regards the performances related to the key aspects, they all will reach the maximum score, as indicated in the summary in the Table 7.

Table 7 – ATM and UTM integration key aspects scores in 2050 timeframe

	ATM	UTM
Physical integration	★★★★★	★★★★★
Network integration	★★★★★	★★★★★
Rate integration	★★★★★	★★★★★
Information integration	★★★★★	★★★★★
Institutional integration	★★★★☆	★★★★☆

For this period there will be a capillary network of stations, which are the collectors of all technologies and incorporate all services, allowing passengers to change means of transport in an easy way.

The network will be completely integrated and therefore also the planning of the routes and the schedule will foresee the connection with all the other systems modes. The ticket integration will be full, now the passenger will have only to take care of managing the departure and arrival place, and the management of any kind of disruptions will be totally transparent to the user. The information management will be fully integrated, one of the fundamental aspects in the case of intermodal travel.

Eventually, the only aspect that cannot be predicted with accuracy is linked to institutional integration because it can also be influenced by political and commercial dynamics that are independent form technological progress. For this reason, the achievement of the maximum score is not sure.

9 Disruptions considerations

9.1 Most common incidents and emergencies

This section covers the aspects of disruptions affecting regular operation of the system. It contains indication both on main reasons of expected disruption grouped into main categories as well as the possible results for the entire system and its functionalities.

Expected system specifications

Highly digitalised system and its components with Internet of Things (IoT) technologies applied will allow for comprehensive, real-time and continuous monitoring of system functions enabling fast and accurate identification of malfunctions of various nature on very initial stage of development. Moreover, the redundant and highly reliable system architecture supported by application of proactive approach (unintended event precursors identification) will lead to the following expected characteristics of internally originated disruptions:

- Technical failures affecting intended operations of transport modes will be less frequent than today. Increased complexity of the system components will be compensated by application of more advanced safety and reliability solutions.
- Strongly transport-efficiency oriented system architecture will strive for minimisation of possible severity of any expected malfunctions, despite the original reason of the malfunction. It can be expected that internally originated disruption will have limited (local) range in terms of fulfilling transportation needs by the integrated, multimodal, metropolitan transport system.
- Human factor will be eliminated by introduction of fully automated traffic in all integrated modes of transport. Non-automated traffic will be isolated in order to not affect operation of integrated, multimodal transport system.

Expected operational environment specifications

In the following sections, both natural and human resulted (intended) factors affecting daily operation of the system will be specified. The reasons will be divided into two main groups: natural environment and security related aspects (including both physical and cybersecurity issues).

9.1.1 Natural environment

Predicted and also more and more often observed changes in climate on the earth are connected with specified natural phenomena. Most of them represent potential to directly or indirectly significantly affect functioning of numerous technical systems including transport.

According to the numerous analyses and models of climate change [142], the most crucial consequences of climate changes are:

- **Increase in global temperatures**. In general, climate models predict that increases in temperature will be higher over land areas than over oceans and seas, higher in interiors of continents than in coastal areas, and higher when going from the tropics to the polar region in the Northern Hemisphere.

- **Changes in precipitation patterns**. The potential consequences of climate change for precipitation patterns are more complex, and depend largely on continental geometry (vicinity of water) but also on the vicinity and shape of mountains and on wind flow direction. In general, the existing climate models predict that precipitation will increase in areas adjacent to the Polar Regions, and will decrease in areas adjacent to the tropics.

- **Sea level rise**. Global sea level rise in 2100 for the six SRES (Special Report on Emissions Scenarios) marker scenarios ranges between 0.18 and 0.59 m above 1990 levels [143].

As it is indicated in [144], the main concerns coming from changing climate are the increased number of extreme weather phenomena occurrences related to temperature (annual and even daily amplitude), extremely strong wind as well as severe precipitation.

Looking on the European continent, its location on the globe and geographical characteristics, it can be seen that climate changes and the degrees to which they occur will be different for different regions leading to various consequences for all transport modes.

Impact on road transport:

- Faster road infrastructure degradation due to higher temperature amplitude leading to more frequent infrastructure maintenance works.

- Floods and intensive precipitations or strong wind decreasing the transport efficiency and in extreme situations leading to road infrastructure malfunctions or destructions. It can also create more demanding conditions for automation driving systems.

- Increased energy consumption in vehicles resulting from higher or lower outside temperature (more frequent air conditioning need). More demanding operational conditions leading to higher probability of technical failure and possibly decreasing the fuel cells lifespan.

Impact on rail transport:

- Faster railroad infrastructure degradation due to higher temperature amplitude leading to more frequent infrastructure related disruptions and maintenance breaks.

- Floods and intensive/extreme precipitations and strong wind leading to railroad infrastructure malfunctions and destructions occurring more frequently.

- Increased energy consumption in vehicles resulting from higher or lower outside temperature (more frequent air conditioning need). More demanding operational conditions leading to higher probability of technical failure and possibly decreasing the fuel cells lifespan.

Impact on waterborne transport:

- Extreme water levels will occur more frequently leading to increasing the cost of water transport and/or more frequent operational breaks.

- Floods, intensive/extreme precipitations and strong wind will lead to more often malfunctions and destructions of waterborne transport infrastructure.
- Increased energy consumption in vehicles resulting from higher or lower outside temperature (more frequent air conditioning need). More demanding operational conditions leading to higher probability of technical failure and possibly decreasing the fuel cells lifespan.

Impact on air transport:

Today the weather is the most frequent reason of delays in air transport. Intensification of natural phenomena like storms, wind gusts, precipitations or other phenomena affecting visibility will require putting additional effort into aviation industry in order to assure at least the same level of safety and operational efficiency of air transport. Furthermore, the introduction of UAM services operating on lighter aircraft over densely populated and more turbulent areas makes the question of weather resilience even more challenging. In detail, climate change will turn into the following adverse weather conditions:

- Stronger wind leading to more often and unpredictable turbulences, wind gusts, varied travel speeds. Possibly affecting the aircraft structure and its lifespan (leading to increased probability of structural failure).
- Higher temperature amplitude including more frequent icing conditions, increased energy consumed for sustaining comfortable conditions for passengers and crew. More often need for aircraft pre-flight de-icing.
- Intensification of precipitations limiting operation of airports leading to increased cost related to airport air-side maintenance. Reduced visibility.
- Poorer visibility conditions, i.e. fog, smog, etc., resulting with stronger needs for precise approach and landing systems.

9.1.2 Security aspects

Under the consideration of security aspects, two main issues have to be taken into account:

- increased terrorist attack probability resulted from global economic situation;
- increased systems vulnerability for cyber-attacks.

For what concerns the terrorist attack probability, as observed in [6], it is expected high risk of terrorism and fundamentalism as an effect of unsolved societal issues, with destructive effect on economic growth, especially in less stable countries. As the history indicates, the public means of transport are often considered as relatively easy as not at all or poorly secured target of attack giving at the same time ability to affect big number of people directly by hurting them or indirectly by destabilisation of transport system (and not only) of the city. Congestion resulting with crowding during peak hours is additional conducive factor.

As it is also proved by the numerous historical terrorist attacks (as that taken place in Brussels airport in 2016), they are often very severe and result with victims and long-lasting disruptions in transport services (destruction of infrastructure). Other indirect effect is mental, fear of travelling by attacked transport mode, affecting and misbalancing the demand distribution among available transport modes.

For what concerns, then, the cyber-attacks, as highly digitalised and based on algorithmic governance approach, the integrated transport systems will be very vulnerable for cyber-attacks. Theoretical possibility of getting access to sensible (personal) data or taking control on part of complex system raises serious concerns and the cost of system security assurance is seen as more demanding in terms of development effort than the transport management system itself. Such considerations apply in equal degree in all transport modes, especially those automated.

As related to virtual integration of transport system, this issue is addressed in more comprehensive way in the X-TEAM D2D deliverable D4.1 [10] and will be analysed with more details in the subsequent deliverable D4.2.

9.2 Possible mitigation strategies

The section above indicates that, besides new technologies able to take transport integration on higher level, the 2050 time horizon reality will bring the new challenges related to the risk carried by evolving climate as well as by increased global social tensions and cybersecurity threats deriving from the higher digitalization levels reached over time in the ATM and UTM as well as in the overall intermodal transport system. In the following sections some possible mitigation strategies will be outlined.

9.2.1 Natural environment mitigation strategies

Despite the increasing global awareness of changing climate and more and more political effort aiming at reversing the negative climate and weather trends, there is a serious risk of increased cost of adverse weather mitigation means. In order to minimise the consequences there is a need to take a set of actions both on the level of particular system components as well as the complex system architecture.

Level of system components

Expected changes in daily weather require development of dedicated technological solutions, to adapt to new conditions.

In surface transport they should assure:

- More durable and weather resistant transport infrastructure (on extremely high or low temperatures, heavy precipitations, strong wind, etc…), like road pavement or rail road tracks, supported by ICT solutions aimed at faults detection/prediction.
- At least the same risk of technical malfunction due to more extreme operational conditions, achieved by more durable parts/components and/or fault detection/prediction systems or redundancy, on the level of both components as well as complex system.
- Decrease of the energy consumption used by air conditioning systems in all surface modes of transport.

In air transport the new solutions should cover:

- The same issues as in case of surface transport modes in terms of durability of both infrastructure and system components as well as in relation to air conditioning.
- Aircraft configurations enabling safe operations in strong wind conditions.
- More affordable approach and landing systems enabling operations in poor visibility conditions.

Level of complex system

As considered as one of the most critical metropolitan system, transport system architecture should enable:

- Independent operation of all modes (in terms of critical resources required).
- More focus on sustainability in transport to alleviate adverse trends e.g. higher energy needs.
- Increased flexibility, i.e. ability to shift supply among particular modes, to mitigate severity of system components exclusions resulted from e.g. partial infrastructure destroy.
- Access to all data considered as necessary for accurate and reliable prediction of operational conditions like weather, especially in relation to extreme and potentially dangerous weather phenomena. For example: incorporating the weather nowcasting to the process of prediction of runway friction and landing roll distance (SESAR Pj04, Sol25).

9.2.2 Security related mitigation strategies

With reference to possible mitigation strategies to be applied in order to both reduce the probability as well as the severity of terrorist attack, the following strategies should be considered:

- To reduce the probability of terrorist attack, the improvement of security of passenger terminals e.g. by adaptation of technologies used in airports to reduce the risk of bringing dangerous materials. It can be supported by digital access systems disabling entry to passenger terminal for unauthorised person driven by face recognition systems (e.g. for suspicious people or without valid ticket).
- To minimize the severity of terrorist attack, it should be avoided crowds to minimise number of potentially affected people and also because the crowds are potentially more likely targeted by terrorists. Smooth, integrated multimodal transport adapting supply to nowcasted real-time demand allows for minimisation of crowd also during peak periods.
- In addition, transport supply diversity and functional redundancy needs to be used to reduce the severity of terrorist attack, through independent operation of all modes or other transport system components (in terms of critical resources required). For instance: sectoral automation of traffic assuming independence on non-automated part.

With reference to possible mitigation strategies to be applied with respect to cybersecurity attacks, these will be considered in future activities under the project WP4.

10 Summary and conclusions

In this section, the conclusions of the document are emphasized.

In particular, with regard to Task 3.1, the following achievements have been obtained:

- Identification has been achieved of potential technological solutions over the three time horizons (baseline 2025, intermediate 2035, and final 2050) considered for the incremental ConOps development in Task 3.2.
- Identification of the barriers has been achieved, in terms of regulations and operational standards for aircraft intended to operate in UTM system (with regard to performance and equipment, both for manned and UAM). Such barriers definition has been based on Task 2.4 (as reported in the D2.1 document [6]).
- Enabling projects have been identified and the most relevant projects or activities addressing the barriers have been analyzed.
- Fulfilment of barriers has been addressed and assessed, with the description of degree the projects or activities address the barriers.
- The activities have been completed and the outputs have been reported in the related sections of this document.

With regard to Task 3.2, the following achievements have been obtained:

- definition of the objectives of the Intermodal System;
- setting of the service blueprinting methodology for the intermodal air travel, which will lead to service blueprint definition in the D3.2 document;
- definition of the template of the X-TEAM D2D Service Blue Print supporting the definition of the ConOps;
- definition of a high-level intermodal system architecture, including:
  - associated structure (architecture outline);
  - main elements identification with respect to each of the three time horizons (preliminary architecture components description);
- identification of the role that ATM and UTM will play in the Intermodal System over the three considered time horizons;
- provision of some considerations related to disruptions management (in cooperation and in support of WP4 related activities);
- the ConOps outline activities have been completed and the outputs have been reported in the related sections of this document.

In addition, the project activities will continue in Task 3.2 and in Task 3.3 towards final ConOps definition through:

- final service blueprint definition;
- final integrated transport system high-level architecture and components definition;
- refinement of ConOps about role of ATM and UTM in the Intermodal Transport System;
- extension of disruptions considerations (in cooperation with WP4);
- definition of the high-level system requirements of the Intermodal Transport System (to be confirmed).