EXPLORATORY RESEARCH

SESAR JOINT UNDERTAKING

D5.1 - Concept of Operations Validation Report

Deliverable ID:	**D5.1**
Dissemination Level:	**PU**
Project Acronym:	**X-TEAM D2D**
Grant:	**891061**
Call:	**H2020-SESAR-2019-2**
Topic:	**SESAR-ER4-10-2019**
Consortium Coordinator:	**CIRA**
Edition date:	**27 May 2022**
Edition:	**00.02.00**
Template Edition:	**02.00.03**

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Authoring & Approval

Authors of the document

Name / Beneficiary	Position / Title	Date
Margarita Bagamanova / HvA	WP5 contributor	25 May 2022
Miguel Mujica Mota / HvA	WP5 Leader	14 Apr 2022
Peter Meincke / DLR	WP4 Leader	23 Mar 2022
Gabriella Duca / ISSNOVA	WP5 contributor	20 Mar 2022
Raffaella Russo / ISSNOVA	WP6 Leader	20 Mar 2022
Mario Ciaburri / ISSNOVA	WP5 contributor	20 Mar 2022
Vittorio Di Vito / CIRA	Project Manager / WP3 Leader	30 Mar 2022
Roberto Valentino Montaquila / CIRA	WP5 contributor	30 Mar 2022
Giovanni Cerasuolo / CIRA	WP5 contributor	30 Mar 2022

Reviewers internal to the project

Name / Beneficiary	Position / Title	Date
Bartosz Dziugiel / ILOT	WP2 Leader	14 Apr 2022
Vittorio Di Vito / CIRA	Project Manager / WP3 Leader	14 Apr 2022
Peter Meincke / DLR	WP4 Leader	14 Apr 2022
Fares Naser / DLR	WP3 contributor	14 Apr 2022
Vittorio Sangermano / ISSNOVA	WP5 contributor	14 Apr 2022
Luigi Brucculeri / D-FLIGHT	Project member	14 Apr 2022
Edoardo Fornaciari / D-FLIGHT	Project member	14 Apr 2022

Reviewers external to the project

Name / Beneficiary	Position / Title	Date

Approved for submission to the SJU By - Representatives of all beneficiaries involved in the project

Name / Beneficiary	Position / Title	Date
Vittorio Di Vito / CIRA	Project Manager / WP3 Leader / Main PoC CIRA	19 Apr 2022
Bartosz Dziugiel / ILOT	WP2 Leader / Main PoC ILOT	22 Apr 2022

Peter Meincke / DLR	WP4 Leader / Main PoC DLR	22 Apr 2022
Miguel Mujica Mota / HVA	WP5 Leader / Main PoC HVA	22 Apr 2022
Raffaella Russo / ISSNOVA	WP6 Leader	22 Apr 2022
Gabriella Duca / ISSNOVA	Project member / Main PoC ISSNOVA	22 Apr 2022
Luigi Brucculeri / D-FLIGHT	Project member / Main PoC D-FLIGHT	22 Apr 2022

Rejected By - Representatives of beneficiaries involved in the project

Name and/or Beneficiary	Position / Title	Date

Document History

Edition	Date	Status	Name / Beneficiary	Justification
00.00.01	19Jan2022	Template	Margarita Bagamanova / HvA	Proposed template distributed
00.00.02	20Mar2022	Draft	Gabriella Duca / ISSNOVA	Passenger assumptions updated
00.00.03	23Mar2022	Draft	Peter Meincke / DLR	ConOps components description updated
00.00.04	30Mar2022	Draft	Vittorio Di Vito / CIRA	ConOps ATM concept updated
00.00.05	01Apr2022	Draft	Margarita Bagamanova/ HvA	Template updated to v. 02.00.03
00.00.06	09Apr2022	Draft	Miguel Mujica Mota/ HvA	Conclusions updated with Advisory Board feedback
00.00.07	14Apr2022	Draft	Margarita Bagamanova/ HvA	Added figures in section 4
00.00.08	15Apr2022	Draft	Margarita Bagamanova/ HvA	Final version disseminated for approval
00.01.00	22Apr2022	Final	Miguel Mujica Mota/ HvA	Final version approved for submission
00.01.01	23May2022	Draft	Margarita Bagamanova/ HvA	Added requested clarifications on the project scope
00.01.02	24May2022	Draft	Margarita Bagamanova/ HvA	Added requested clarifications on the ConOps assumptions
00.01.03	26May2022	Draft	Margarita Bagamanova/ HvA	Final version disseminated for approval

EUROPEAN PARTNERSHIP

Co-funded by the European Union

00.02.00	27May2022	Final	Margarita Bagamanova/ HvA	Final version approved for submission

X-TEAM D2D

EXTENDED ATM FOR DOOR2DOOR TRAVEL

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

Abstract[1]

X-TEAM D2D project aimed to define, develop, and validate 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 goals. 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 aims contributing to this goal by providing and preliminarily validating a ConOps for a specific case of a seamless door-to-door mobility in urban and suburban (up to regional) environment, i.e., X-TEAM D2D target scenarios address 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 networks serving Urban and Extended Urban mobility, considering the transportation and passengers service scenarios envisaged for the following decades: baseline (2025), intermediate (2035), and final (2050) time horizons. The target ConOps encompasses both the transportation platforms integration concepts and the innovative seamless mobility as a service, including ATM concepts.

The X-TEAM D2D project developed a simulation-based platform for validating the proposed ConOps, considering the most relevant elements of the future transport, such as interfaces mode-mode, high-level network model, and passenger-centric paradigm. In particular, the project WP5 activities addressed the validation of ConOps supporting the seamless integration of ATM into an overall intermodal network from the passengers' perspective and overall multimodal system performance based on the corresponding KPAs and KPIs.

The deliverable D5.1 reports the outcomes of the WP5 activities and describes the results of the validation of the Concept of Operations for ATM integration in the intermodal transport system. Furthermore, this document emphasizes the conclusions and recommendations arising from the preliminary ConOps validation results.

[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.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Table of Contents

List of Tables

List of Figures

1 Introduction

1.1 Document scope

X-TEAM D2D (eXTEnded AtM for Door2Door travel) project has been funded in the SESAR 2020 Exploratory Research ER4-2019 Call for Research Projects [1]. It addresses the topic ER4-10-2019 "ATM Role in Intermodal Transport," under the ATM Excellent Science & Outreach work area. The project has been funded under Grant Agreement No 891061.

This deliverable aims to report the results of the validation activities for the Concept of Operations defined in the project and reports the outcomes of the studies carried out in Task 5.1 “Benchmark model and performance indicators definition”, Task 5.2 “Evaluation of Extended ATM transport system performances”, and Task 5.3 “Conclusions and recommendations”. Activities of all three tasks have been concluded.

1.2 Acronyms

A-CDM	Airport Collaborative Decision Making
A2D	Airport-to-door
APT	Airport
ATM	Air Transport Management
CCAM	Connected, cooperative, automated mobility
ConOps	Concept of Operations
CVSF	ConOps validation simulation framework
D2A	Door-to-airport
D2D	Door-to-door
eVTOL	electric vertical take-off and landing aircraft
KPA	Key Performance Area
KPI	Key Performance Indicator
LCC	Low-Cost Carrier
PAX	Passengers
PRM	Person with Reduced Mobility
SRA	Short-range airlines
TRL	Technology Readiness Level
UAM	Urban Air Mobility
VFR	Visiting friends and family
X-TEAM D2D	eXTEnded AtM for Door2Door travel
WP	Work Package

EUROPEAN PARTNERSHIP

Co-funded by the European Union

2 Summary of Concept of Operations under study

During the execution of the X-TEAM D2D project, the ConOps for seamless integration of ATM into an overall intermodal transport system has been defined in project deliverables 3.1 and 3.2 [2], [3]. In parallel to that, the ConOps for ATM service to passengers in intermodal transport has been outlined and described in deliverables 4.1 and 4.2 [4], [5]. The summary of these ConOps is briefly outlined in the following sections. It is important to note that these ConOps were developed under the assumptions considered according to the corresponding research state and trends existing in 2020-2022. Therefore, the ConOps outlined in this document could be modified if the situation in 2035 and 2050 is not as the one envisaged during the project execution.

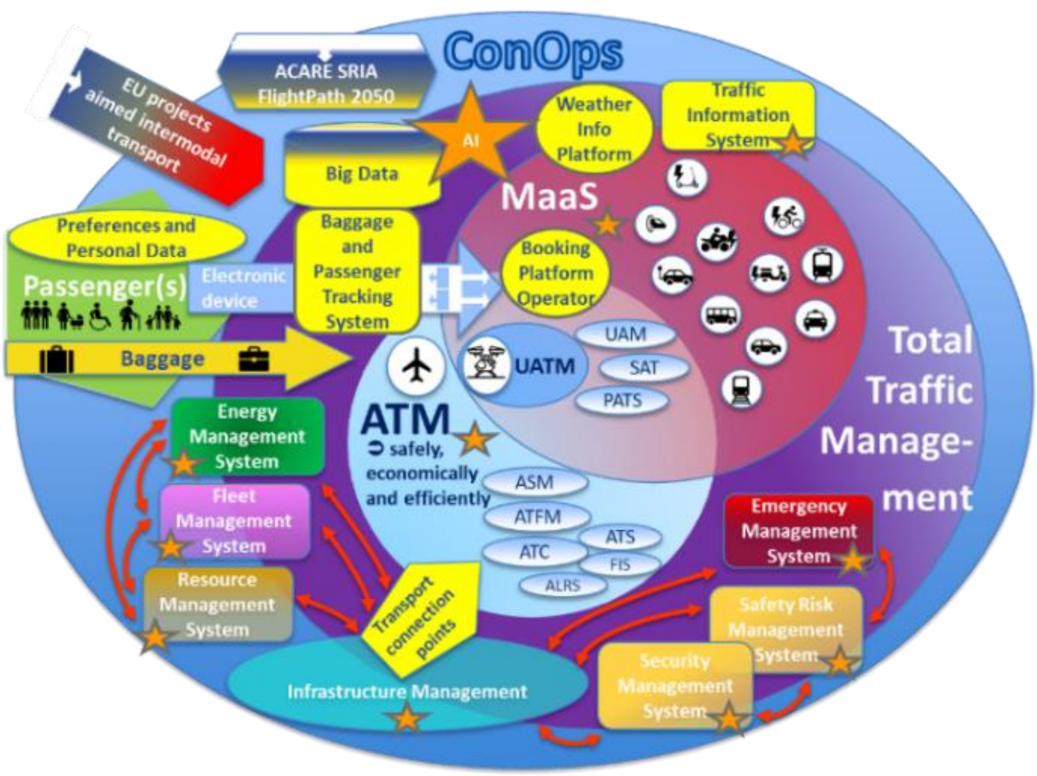
2.1 Components for a Concept of Operations for ATM service to passengers in intermodal transport

In these ConOps, the focus is on the passengers so that sustainable success is achieved if this system attracts and retains the confidence of customers/passengers and other relevant interested parties. An increase in satisfied and loyal customers means a flourishing overall system and thus added value for the other stakeholders in the system [6], [7]. Every aspect of passenger interaction offers an opportunity to create more value for the customer. Efficient management and cooperation in the different areas enable optimisation and harmonisation of the overall system [8], [9].

Therefore, the ISO basic concepts and principles for Quality Management Systems (QMS) flow into these ConOps. They represent a modern form of work organisation and corporate governance with which the management of any organisation, including the transport sector, can achieve its goals [8], [10]. The management and service components of the ConOps are shown in Figure 1 and defined in the following context and, if possible, referred to SESAR.

EUROPEAN PARTNERSHIP

Co-funded by the European Union



AI★	Artificial intelligence	FIS	Flight Information Service
ALRS	Alerting Service	MaaS	Mobility as a Service
ASM	Air Space Management	PATS	Personal Air Transport System
ATFM	Air Traffic flow management	SAT	Small Air Transport Research
ATC	Air Traffic Control	SMS	Safety Management System
ATS	Air Traffic Services	SRM	Safety Risk Management
ATM	Air Traffic Management	UAM	Urban Air Mobility
ConOps	Concept of Operations	UATM	Urban Air Traffic Management

Figure 1. Concept of Operations supporting the seamless integration of ATM and Air Transport into an overall intermodal network

2.1.1 Artificial Intelligence

The artificial intelligence component will be necessary for the operational concept of the ATM service for passengers in intermodal transport. Many AI application possibilities can make mobility safer, more ecological, more efficient, more comfortable, more intelligent and more resource-saving. Moreover, that means not only the development of autonomous means of transport but also the implementation and control of inter- and multi-modular networked management systems [11].

2.1.2 Resource Management Systems

Resource management focuses on Quality-of-Service requirements, among others. An efficient resource management mechanism for vehicular multimedia applications is essential to obtain the most valuable and complete traffic information, including location coverage.

Resource management should identify resources required to achieve the organisations' objectives. To ensure that resources are used effectively and efficiently, processes are required to provide, allocate, monitor, evaluate, optimise, maintain and protect these resources [8]. For example, an efficient resource management mechanism for vehicular multimedia applications is essential to obtain the most valuable and complete traffic information, including location coverage.

SESAR provides open information standards for a centralised wireless system to disseminate passenger flow information at major airports to include ground transportation connectivity, weather, delays, parking availability and check-in times within a single network.

2.1.3 Traffic Information System

The exchange of information between the infrastructure and transport vehicles of all types, including air vehicles, is generally considered an enabling technology to reduce accidents, congestion, and peaks in the long term and improve traffic efficiency.

Under SESAR, it is expected that a more significant number of aircraft will operate with reduced separation thresholds between aircraft within a given airspace. The new concept of operations also allows aircraft the flexibility to change flight routes (or flight plans) in response to changing conditions. In addition, different aircraft would have very different navigation capabilities due to different equipment levels. With such complex scenarios in future air traffic control operations, it would be essential to have a compliance monitoring tool to monitor aircraft movements.

2.1.4 Mobility as a Service

The mobility services can be provided by different suppliers and are to be offered and billed as a combined, multimodal service. This requires joint route planning of the individual mobility services and their joint billing [12].

Most users will expect a comparatively seamless mobility experience on the ground, on the water, and in the air. To deliver this experience, providers and agencies will need to offer and implement an efficient Mobility as a Service (MaaS) that can integrate all available modes of transportation.

2.1.5 Energy Management Systems

Energy management will play a key role in achieving efficient energy consumption of electric vehicle technology on the ground and air. Another issue is the charging infrastructure and power plants needed to support the electrical infrastructure. For this purpose, all possible energy sources must be statistically recorded, planned and controlled from a coordination centre.

2.1.6 Fleet Management System

The fleet management of these ConOps must ensure that all vehicles within the system and the integrated providers are used economically and that sufficient transport capacity is available for all processes [13], [14].

2.1.7 Emergency Management System

The ConOps system must be resilient and robust to respond to failures and/or interruptions. This includes contingency measures to ensure continuity of operations in the event of major outages, natural disasters, security threats or other unusual circumstances.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Following SESAR, a balance of reliability, redundancy, and procedural backups should ensure security during a failure of individual systems or components. Ultimately, SESAR provides a high availability system and requires minimal time to restore functionality in case of disruptions.

2.1.8 Safety Management System

Safety is promoted by using an integrated Safety Management System approach for identifying and managing potential hazards. This includes equipment, organizational, operational or systems problems.

Specifically, SESAR uses a formal, top-down, business-like approach to manage safety risk, including systematic procedures, practices, and policies for safety management.

2.1.9 Security Management System

Secure infrastructure (e.g., train stations, terminals, airports, and take-off-and-landing areas) must have an integrated facility security system that can be adapted to different capacities, accesses and risk situations.

2.1.10 Infrastructure Management System

Intermodal ground access to all transport connection points is essential for intermodal networks. Functioning and passenger-appealing transitions in the form of transport interconnection points are needed to link transport networks within a regional system and enable more efficient traffic flow.

Joint management of the infrastructure would bring precise quality control and set the standards in the system [15].

2.1.11 Authoritative Weather Info Platform

This integration of weather information platform, combined with probabilistic forecasts to account for weather uncertainty and improved forecast accuracy, minimises the impact of weather on traffic.

2.1.12 Baggage and Passenger Tracking System

The passenger and baggage tracking system allow baggage handling to be carried out in a remote area of the airport if required. This increases capacity, reduces check-in time, reduces staffing requirements, and enables transparency for passengers.

This system aims to ensure that, by taking greater account of passengers' preferences, safety is improved, and capacity and operational efficiency are increased. This is achieved by building processes and systems to help passengers realise their preferences. In addition, information is collected, collated, monitored, evaluated, and shared through the management systems. Research and analysis will determine the appropriate division of tasks between systems. This will include determining when decision support is needed to assist humans and when functions must be fully automated.

2.1.13 Interactions and relations between the management systems

The management systems must interact, or the actors and systems must interact with one another. This interaction is closely linked to the concepts of communicating, acting, planning, working with each other and – finally – informing one another.

For example, the infrastructure management system must work closely with the energy, fleet, and resource management systems since there are many relations, similarities and intersections that complement and overlap or influence each other. These interactions also apply to emergency, security, and safety management systems. This mutual interaction should be aimed for and used for all management systems in this overall system.

2.2 Extended ATM Concept of Operations for passenger service

This section describes the elements of the ConOps and their relationships according to the planned architecture of the intermodal transport system. The three time horizons (2025, 2035, 2050) considered in the project are differentiated.

The management systems, the tools, and the "intelligence" of the algorithms, which will become the intermodal system, play a decisive role in achieving the ambitious goal of providing complete traffic management for a door-to-door connection in up to four hours. The elements are to be viewed broadly, as service tools are also included, for instance. While new technologies will improve the means and infrastructures, it is also evident that the system's functioning depends heavily on service quality [15]–[17].

Figure 2 shows the ConOps with the management systems considered in this article (coloured boxes) over the time horizons. The white boxes show the management systems and tools discussed in detail in the upcoming research paper.

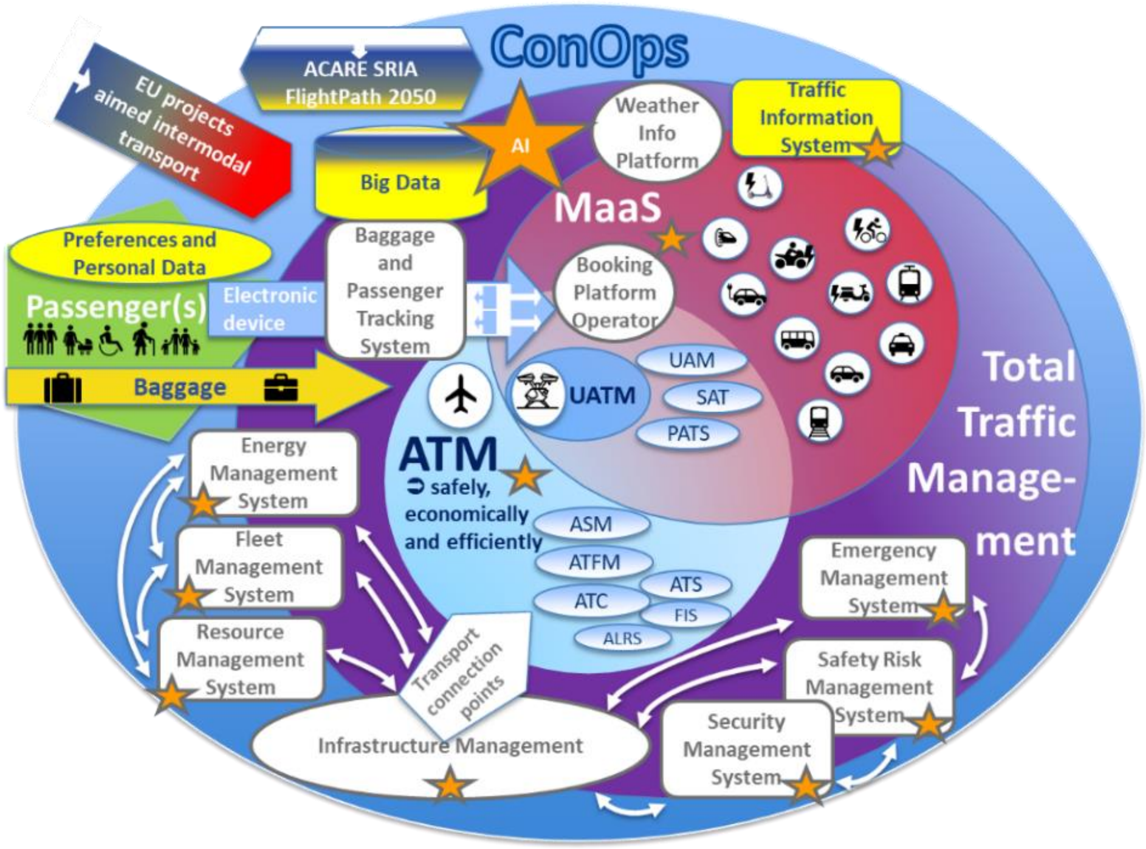


Figure 2. ConOps version of the management and service systems

2.2.1 Architecture outline in the 2025 timeframe

In 2025, the implementation of electric vertical take-off and landing aircraft (eVTOL) for UAM operation will occur. Only on some specific routes UAM will be implemented for testing and demonstration purposes. These UAM operations will be managed with procedures and technologies available within the current ATM paradigm (either local or international). New mobility services (NMS), i.e. car-sharing, ride-hailing, bike-sharing, e-scooters, e-bikes, will gain user interest and take a significant share in the transport system. Some possible services could have an important impact on multimodal mobility. First light MaaS activities, e.g., single ticket, pricing by optimising travel costs of different modes, ticketing interoperability (flexible in case of disruptions) and integrated tickets will be available in some areas. There is still a high difficulty integrating the ATM and U-Space system.

There is still a lack of tools to exchange and use data between the different transport modes in the immediate future. In addition to the passengers, the whole system would benefit considerably from an improvement in this condition. The efficiency of the transport process still depends on the passenger’s ability to manage their journey. Unfortunately, ATM operations have not yet become passenger-centric, partly because performance targets did not consider the impact on passengers. In addition, the complexity of the ATM network does not allow for the desired response in the event of a disruption. The existing ATM works with a well-established and proven safety management system, but it does not allow for rapid developments and implementations. In contrast, U-Space is innovative and fast, but its level of security and robustness is not defined/validated.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

The fact that airspace will be shared between manned and unmanned aircraft when U-Space is introduced makes it necessary to identify and confirm the roles of U-Space and ATM in terms of airspace and traffic management responsibilities and functions. Although these services will likely need to interact, there must be no overlap of conflicting or incompatible services or areas of responsibility.

During 2025, conformance monitoring will rely on current Air Traffic Management - Communication, Navigation and Surveillance (ATM CNS) capability and ATM and regulatory reporting mechanisms. In 2025, there will be an opportunity to increase surveillance and communications coverage by implementing systems such as Automatic Dependent Surveillance-Broadcast (ADS–B) and other communications infrastructures. ADS-B does not necessarily scale well with high traffic density, and coverage is possibly insufficient for all phases of flight. Onboard UAM vehicle systems will be able to collect and disseminate additional information that can be used to inform conformance monitoring. However, a data collection system will need to be implemented. It will be necessary to define where and/or under what scenarios Conformance Monitoring will be necessary.

Scenarios could include adherence to routes in accordance with noise abatement procedures. Conformance Monitoring capabilities established in 2025 would provide evidence that would support the safety and/or community acceptance for moving UAM operations to 2035 (similarly between 2035 and 2050). MaaS will only be available in some regional areas for a part of the transport modes. The continuation of the C-ITS strategy for Cooperative Intelligent Transport Systems will promote international cooperation with other major regions of the world on all aspects of cooperative, connected, and automated vehicles and will decisively advance further development of a Traffic Information System. Urban transport (light rail, metro, but also trams and regional commuter trains) is still characterised by a highly diversified landscape. At least a certain convergence in architectures and systems can be observed. In some cases, these points are linked to the safety of urban transport systems. In this context, “safety” is seen as anything dealing with the methods and techniques to prevent accidents. “Security” is concerned with the protection of people and the system from criminal acts. State of the art has been brought together and extended in harmonised and agreed to standard security packages. Thus, a coherent and coordinated hazard and risk analysis were established, and agreed security requirements were defined for the security-relevant functions of an urban managed transport system. In order to achieve such an allocation of safety requirements, it is necessary to create a functional and object-related safety model for an urban guided transport system.

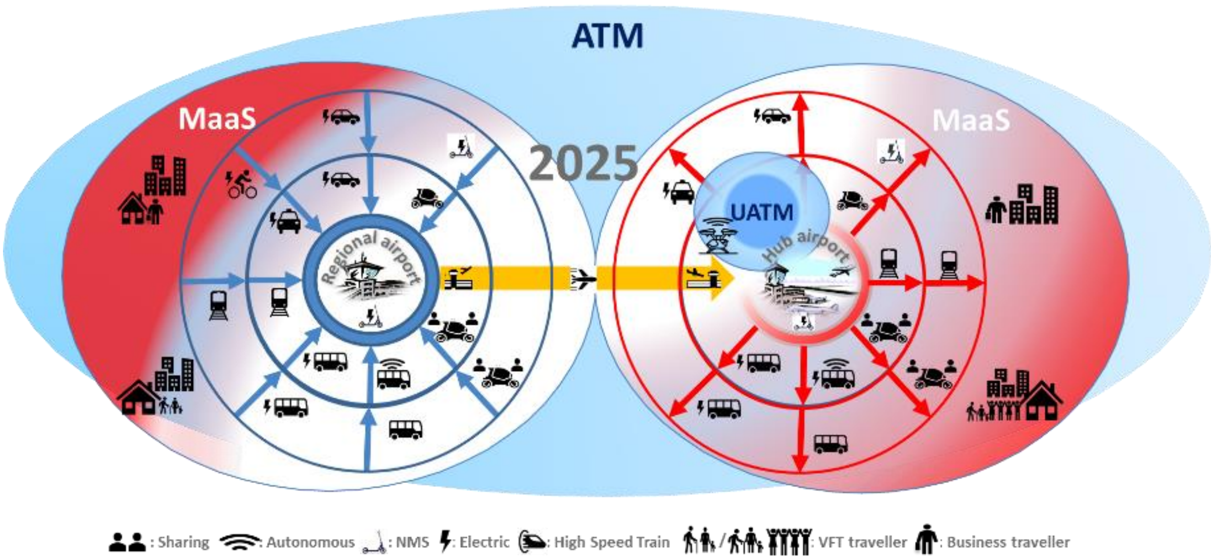


Figure 3. Time horizon 2025 on the way to total traffic management

2.2.2 Architecture outline in the 2035 timeframe

Horizon 2035 requires new ATM procedures and/or technologies not currently used by ATM and will introduce Urban Air Traffic Management (UATM) Services to support UAM operations. These services will vary in service type and maturity, from initial procedures and services to full implementation. Depending on the region, it will not be possible everywhere to reduce the workload of air traffic control (ATC) with the available resources. Trials of new procedures and technologies will be needed during 2025 to support the case for 2035 operations.

In 2035, a new ATM model will emerge with the support of new technologies and standards. Fundamental to this will be support for ATM Data Services Providers (ADSP). The terrestrial component of air-to-ground communications will require high bandwidths. The new architecture will allow resource sharing across the network and more stable service delivery to all airspace users.

The Advanced U-Space services will be operational across Europe. In contrast to the time horizon 2025, a passenger preparing for an intermodal journey in 2035 will be able to use a U-Space for his or her journey. In 2035, Conformance Monitoring will provide an ongoing set of information to manage the operational safety risk of UAM operations. There will be an opportunity to increase surveillance and communications coverage for all stakeholders (including the pilot) by implementing current and new communications and surveillance infrastructure (e.g., new cooperative surveillance technology).

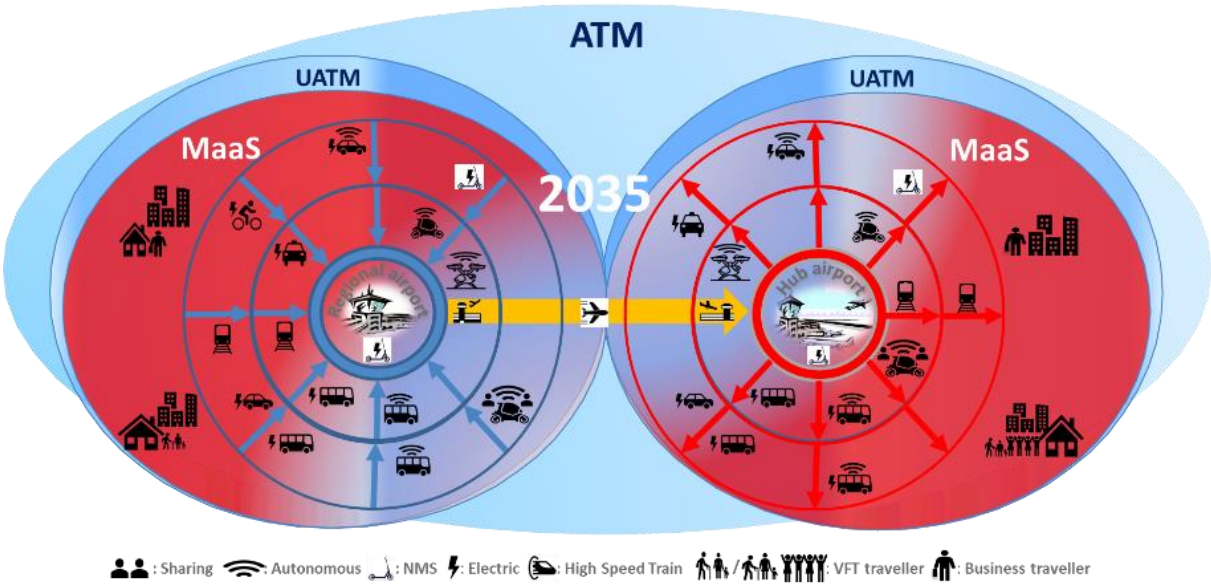


Figure 4. Time horizon 2035 on the way to total traffic management

2.2.3 Architecture outline in the 2050 timeframe

For the 2050 time horizon, intermodal travel is characterised by a full range of services. The management systems will bring traffic management to a much higher level.

By the 2050 time horizon, a highly automated ATM system with an all-weather operation and a safety level above today's will be available. It will be service - and passenger-oriented management, relying on high connectivity, automation, and digitalization.

U-space complete services will be available. C-ITS traffic systems will use all aspects of cooperative, connected, and automated vehicles. The collected data will bring the traffic information system to an excellent level. In addition, strategic planning of traffic flows will be improved, reducing the imbalance between capacity and demand. Based on accurate and complete data, changes and disruptions can be resolved without loss of travel time.

Mobility-as-a-Service will be possible for every traveller for door-to-door travel, including a flight segment (Figure 5).

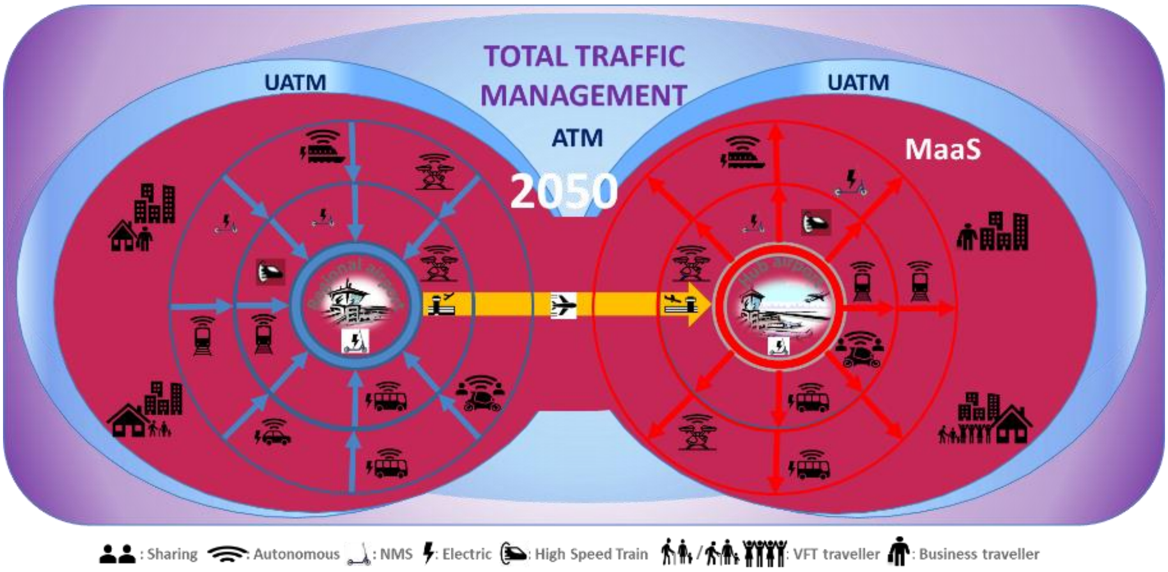


Figure 5. Time horizon 2050 on the way to total traffic management

In addition, Figure 6 shows the optimal configuration of the ConOps with all their management systems, instruments, and applications as an extended ATM operating concept for passenger services, as described in this document.

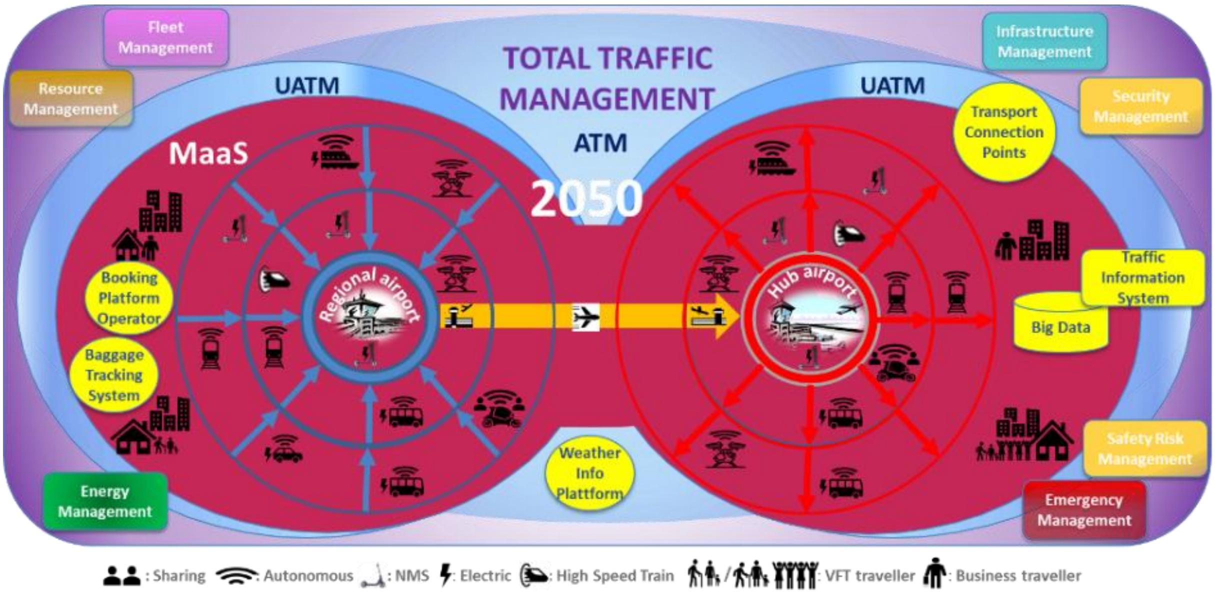


Figure 6. Total traffic management in 2050

3 Passenger profiles under study

In the ConOps validation study, the ConOps were assessed according to the technological state assumptions, passenger profiles, and use cases defined in WP2 and described in detail in D2.1 “Future Reference Scenarios and Barriers” [18]. The passenger profile characteristics relevant for the ConOps validation study are summarized in Table 1 for Business travellers and Table 2 for other travellers.

Time horizon	Business Traveller (profile B)
2025	Travels alone (mainly) Has time constraints/target times Has budget limits, but generally, these depend on the business goal of the trip and the role in the company Have a short stay and cabin luggage Might need to work during the travel time Is a frequent flyer/traveller Is an adult (18-70 years), generally in normal health condition (no physical or sensorial impairments) Can be allowed or not to arrange/rearrange his travel plan depending on internal procedures
2035	Travels alone (mainly) Expect a very high comfort standard Expect a very short travel time Has few budget limits Travels for a short stay, with small luggage Is a frequent flyer/traveller Is an adult (18-70 years), generally in normal health condition (minor physical or sensorial impairments) Relies on dedicated business services for travel arrangements (no reservation or payment methods constraints) Has full flexibility for travel plans change
2050	Travels alone (mainly) Expect a very high comfort standard Expect a very short travel time Has few budget limits Might travel for long stays (as short travels for face-to-face meetings will dramatically reduce) with large/heavy luggage Is a frequent flyer/traveller Is an adult (18-75 years) with possible physical or sensorial impairments Relies on dedicated business services for travel arrangements (no reservation or payment methods constraints) Has full flexibility for travel plans change Must comply with environmental performance targets set by his/her company

Table 1. Business passenger profile characteristics

Time horizon	Other travellers (profile V)
2025	Travels in small or larger groups (mainly) Unless specific travel reasons (a ceremony, family issues, etc.) has relatively low time constraints Has budget limits Can have larger/heavy luggage or other items such as sport equipment, walking aids, etc. Might need assistance (children, elderly, disabled people) Can be or not a frequent flyer/traveller Can be of any age range, from baby/children to very elderly Can have any kind of physical or sensorial impairment Is free to arrange/rearrange the travel according to the preferences Might have constraints in payment methods (unavailable credit card/cash, etc.) Might encounter language/communication barriers
2035	Travels in small or larger groups (mainly) Unless specific travel reasons (a ceremony, family issues, etc.) has relatively low time constraints Can have larger/heavy luggage or other items such as sport equipment, walking aids, stroller, etc. Has budget limits Has not constraints for reservation or payment methods Might need assistance (children, elderly, disabled people) Can be of any age range, from baby/children to very elderly Can have any kind of physical or sensorial impairment Is free to arrange/rearrange the travel according to the preferences Is sensitive to environmental footprint of his/her journey Has no communication limitations thanks to technology support
2050	Travels in small or larger groups (mainly) Unless specific travel reasons (a ceremony, family issues, etc.) has relatively low time constraints Has only personal items/small luggage as luggage will be picked up and delivered door to door (except for walking aids/stroller) Has budget limits Has not constraints for reservation or payment methods Does frequent short stay/medium distance travels Might need assistance (children, elderly, disabled people) Can be of any age range, from baby/children to very elderly Can have any kind of physical or sensorial impairment Is free to arrange/rearrange the travel according to the preferences Is sensitive to the environmental footprint of his/her journey Has no communication limitations (due to good education and/or technology support)

Table 2. Other passenger profile characteristics

4 Concept of Operations validation framework

4.1 ConOps validation scope

The developed ConOps cover multimodal transportation systems in three representative time horizons: 2025, 2035 and 2050. Each of these time horizons was assumed to have different technological states and different levels of integration of transportation systems. The summary of these assumptions per time horizon is shown in Table 3, Table 4, and Table 5, respectively.

Horizon	Expected characteristics
2025	The only air mode of transport with the potential to impact the efficiency of the transport system by data sharing is short-range airlines connections, connecting a hub airport with regional one or two regional airports (point-to-point connections executed by LCC airlines). Hub airport connects with the city by numerous modes (trains, bus connections, taxis, etc.). There is no direct access to e-bikes or e-scooters sharing systems from the hub airport. Also, getting car-sharing services requires longer walking trips (due to pressure on cost, contrary to the rental cars). Regional airports provide access to one or a maximum of two public transport services (train, bus). It is easier than in the hub airport to rent a car or use NMS services, including e-bikes or e-scooters (depending on the airport location).

Table 3. Overview of ConOps validation scenarios characteristics 2025

The ConOps consider D2D international travel with the use of air transport involving two types of airports defined as [19]:

- ***Regional airport*** – a non-hub airport without transfer traffic. For modelling purposes, Hannover airport in Germany was taken as a base case for modelling such an airport. In this document, this airport will be referred to as APT-R.
- ***Hub airport*** – an airport that serves as a node for connecting different flight legs for several airlines. For modelling purposes, Schiphol airport in Amsterdam, the Netherlands, was taken as a base case for modelling such an airport. In this document, this airport will be referred to as APT-H.

Horizon	Expected characteristics
2035	A percentage TBD of cars will be electric. Driving performances are highly automated. In urban areas, the car-sharing model will be dominating. In densely populated areas, where car traffic will be forbidden or limited, (electric) micro-mobility means of transport will have a significant share (beside public mass means of transport). Public transport network will be significantly extended, offering a higher level of accessibility for citizens and reducing the length of the first and last legs of multimodal travel. SRA connections will remain the transport mode with the highest potential impact on the efficiency of the transport system by data sharing, connecting a hub airport with one or two regional airports (point-to-point connections). Urban Air Mobility (UAM) for passenger transport in experimental sites will be available in Europe without significant impact on mobility in metropolitan areas. Hub airport connects the city by numerous modes (mostly collective transport means). A percentage of Electric Taxis will be replaced by electric car-sharing and more accessible from the airport terminal (replaced "traditional" rental cars). There is no direct access to e-bikes, e-scooters sharing systems from the hub airport due to the remote location of the hub airport from the city. Regional airports provide access to more than one public transport service (train, bus). Electric shared cars or NMS services, including e-bikes or e-scooters, are commonly used as airport cities develop (depending on the location and size of the airport).

Table 4. Overview of ConOps validation scenarios characteristics in 2035

Horizon	Expected characteristics
2050	All cars will be electric and mostly highly automated and autonomous. In urban areas, the car-sharing model will be dominating. In densely populated areas, car traffic will be forbidden, (electric) micro-mobility (soft) means of transport will be the only personal means of transport with a significant share (besides public mass means of transport). Public transport network will reach the maximum available density to meet increased demand, offering the highest possible accessibility level and shortening the first and last multimodal travel legs. SRA connections operated by zero-emission aircraft will remain the transport mode with the highest potential impact on the efficiency of the transport system by data sharing, connecting a hub airport with regional or two regional airports (point-to-point connections). UAM dedicated to passenger transport will be available in Europe, offering direct access to densely populated city areas. Regional range air travels will also be possible using new concept aircraft, VTOL, multirotor and fixed-wing aircraft, depending on appropriate infrastructure availability. Due to the high operational cost, passenger UAM will be mainly for high-income and high value-of-time PAX and operating between airport and business centres and public services (like HEMS, police). UAM will not significantly impact mobility in metropolitan areas but will be considered essential and often necessary from a social point of view. Hub airport connects with the city by numerous collective, autonomous transport modes complementing electric car-sharing services. From the hub airport, there is no direct access to e-bikes, e-scooters sharing system due to the remote location of the hub airport from the city. Regional airports provide access to more than one collective autonomous transport service (train, bus). Electric shared cars or NMS services, including e-bikes or e-scooters, are commonly used as airport cities develop (depending on the location and size of the airport). Large water reservoirs in metropolitan areas and autonomous ferry services can support the multimodal journey in favourable conditions.

Table 5. Overview of ConOps validation scenarios characteristics in 2050

4.2 ConOps validation process

To use the modelling framework for validating the ConOps, it needs to be validated first. Considering this, the overall ConOps validation process is structured as depicted in Figure 7.

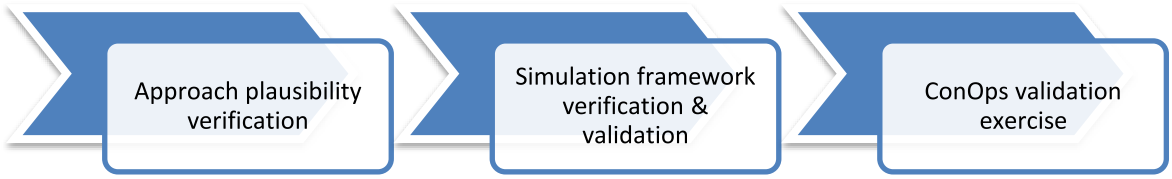


Figure 7. ConOps validation process

4.2.1 Step 1: Approach plausibility verification

The first step is to ensure that the selected approach and parameters will be representable for the evaluation of ConOps. Owing to the nature of the X-Team D2D project, particularly the time horizons of the scenarios proposed, the different scenarios should undergo an exercise that increases the certainty of ConOps as the one described in the project. This activity is called the approach plausibility verification. Such verification was performed by the committee of experts external to the project and invited for this particular task in the form of the Advisory Board. During this activity, consortium partners presented the framework, relevant material, results, assumptions, case studies and model outcomes to experts in different areas to evaluate the approach's plausibility and identify behaviour and obstacles that can be considered unlikely or challenging to happen.

This exercise took place in February of 2022 when the framework was finished and the first results were obtained. The model and material related were evaluated by a group of four experts, members of the advisory board of X-Team D2D:

- Director of Operations Research Department of the National University of Mexico, Mexico
- Professor for Global Supply Chain Management, University of Bremen, Germany
- Professor of Aviation Management, University of LaPlata, Argentina
- Professor of Maritime Studies, The Maritime University of Szczecin, Poland

Each of the experts is known in their areas of expertise ranging from sea to air transport. The details of the activity for validating the plausibility of the approach can be found in the additional document D.5.1.010 named "Validation Plan" [20]. The experts considered the approach plausible, and the details of experts' feedback are discussed in section 7.1.

4.2.2 Step 2: Simulation framework verification and validation

The second step is the verification and validation of the simulation framework. The simulation framework validation can be defined as the evidence "that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model" [21].

Each transport technology was verified according to the data and logic available from public transport operators in Germany and the Netherlands. The simulation framework was considered verified when this activity was performed and agreed to be correct [21]. This activity was performed by WP5 members, discussed with the consortium partners, and agreed on the parameters used. The results of this step are discussed in section 7.2. Furthermore, the framework's representation of the multimodal journeys was analysed using experiments and extracting data from the models. These data were compared to available data of the technologies used in the simulation models. Since the project investigated the impact of future technologies, some data could not be statistically validated against similar data due to its absence. For those cases, the quantitative validation was replaced with a corresponding validation session with experts from the consortium and the Passenger Advisory Group.

4.2.3 Step 3: ConOps validation exercise

The ConOps validation process started when the framework was verified and validated. ConOps feasibility and performance assessment was done according to the methodology described in section 4.3. For this assessment, several transport modalities corresponding to the transportation network in urban and suburban areas of regional and hub airports in 2025, 2035 and 2050 were modelled in the ConOps validation simulation framework (CVSF), described in section 4.4. Each transport mode and its state in the corresponding time horizon was modelled according to the assumptions described in sections 6.1 and 6.2.2.

To validate the ConOps, a series of experiments has been run in CVSF. These experiments simulated the passenger journey in 2025, 2035 and 2050 in three system operations types: normal, ad-hoc disturbance and disturbance five hours before the passengers' departure from home. In each experiment, passengers could use various transport modes according to the use cases described in section 6.1. The systems' performance was assessed using KPIs identified by the consortium experts and described in section 5.

After this activity, the expected performance of the future system could be foreseen, and potential inefficiencies and emerging behaviour that might affect the efficiency of the integration of technologies were identified. The results of performed ConOps validation exercise are discussed in section 7.3.

4.3 ConOps validation methodology

Validation of ConOps developed during the X-Team D2D project constituted an essential part of WP5. The ConOps validation approach consisted of the following elements:

1. ConOps logic
2. Multimodal transportation network conceptual design
3. Modelling assumptions and implementation
4. Simulation framework
5. Experimental scenarios

The ConOps definition (WP3 and WP4) was performed in parallel with ConOps validation (WP5). Therefore, the ConOps validation work followed the cycle methodology shown in Figure 8. This methodology for constructing an accurate model has been developed and applied by the consortium members [22] in the aviation area. The main steps are the following:

1. Problem formulation. In this step, the problem under study should be clearly described, using descriptive elements that help provide a clear understanding of the nature of the problem.
2. Setting objectives. Based on the problem formulation, the analyst should set the objectives pursued by the study. This step is fundamental since it will determine different key decisions, such as the abstraction level and boundaries of the study (i.e., what is included and what is excluded).

3. Model conceptualisation. In this step, the logic of the model and the artefacts that are within the model's scope are defined. The analyst can make use of descriptive tools like flowcharts or Petri nets for this task.
4. Data collection. This step will iterate with the previous elements to identify the data that is required beforehand, what sources of data are available, and which need to be collected or not.
5. Model translation, verification, and validation (V&V). It is in this step that the proposed methodology differs from those presented by other authors. In this case, the models with different abstraction levels are developed and verified. If the data and information are available, then the different models are validated. This step is a combination of models, which can number more than two, but the modelling effort will depend directly on the number of models to be developed.
6. Experimental design. In this step, and once the model(s) are validated, an experimental design is performed, using the different developed model(s) and identifying the outcomes that should be in line with the objective stated. The experimental design must deal not only with the combinatorial nature of the decision variables of each model but also with the outcomes of the interaction of the models once the cycle is progressing.
7. Replications and analysis. This corresponds to the definition of the sample size of the model and the analysis of the data it generates. Compared to standard methodology, this activity is more time-consuming since the number of replications will increase linearly with the number of models in the cycle.
8. More runs. More replication runs are executed to obtain statistically relevant data and consider the impact of all stochastic events in the model.
9. Documentation and reporting. This step relates to the description of the analysis and the reporting of results used by decision-makers.
10. Implementation. In the best situation, the insight gained from the model(s) analysis is implemented in the real system. Due to the low TRL nature of X-Team D2D activities, the project did not include implementation in a real operational environment; however, initial insight into future performance can be identified and used as a steppingstone for future technology development. This action minimises the risk of failure or over-/under-design in infrastructure projects.

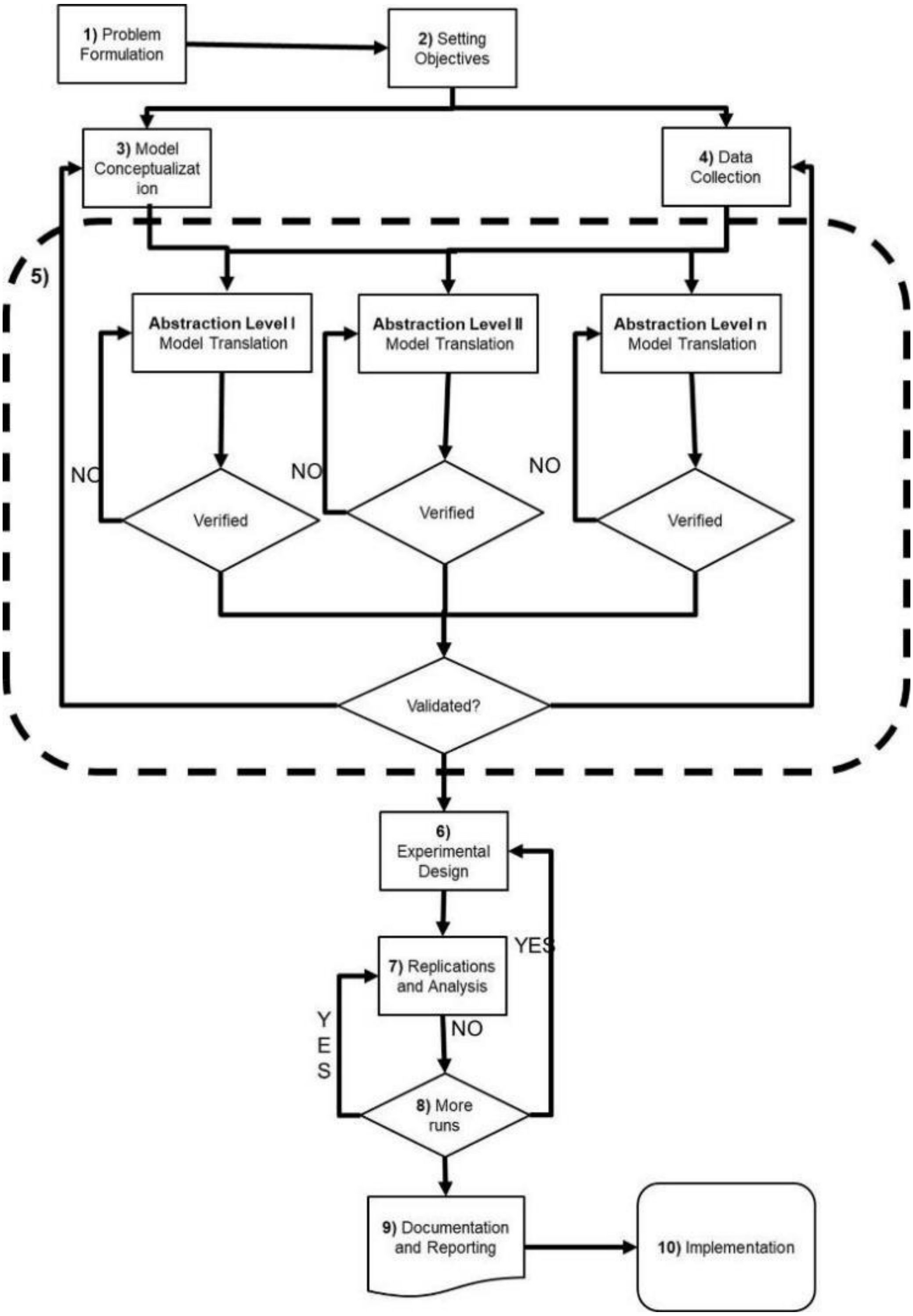


Figure 8. ConOps Validation cycle

After WP3 and WP4 provided the first definition of ConOps, it was conceptualised in process logic and modelling assumptions incorporated into the simulation framework. After this activity, a series of simulation experiments were performed with a set of predefined scenarios, as described in section 6.

4.4 ConOps validation simulation framework architecture

The ConOps validation simulation framework aimed to evaluate the impact of future Concept of operations on the passenger journey. It was implemented in a general-purpose discrete event simulation software. The framework was based on a multiple-layer approach, where first, the existing transportation network was created. Then, future transport technologies were added as an additional layer considering relevant time horizon assumptions and the ConOps. Such an approach allowed simulating different time horizons using the same simulation model, which reduced the required model building time and allowed flexible integration of different transport means into one overall multimodal network that simulated the complete door to door journey.

The structure of the simulation framework is schematically presented in Figure 9. The framework consists of two main models: the first model represents the D2A part of the passenger journey, and the second model represents the A2D part of the journey. The two models are coupled using a weighted edge representing the flight time from a regional airport to a hub airport. This time considered the time between the aircraft take-off at the regional airport and landing of the aircraft at the hub airport.

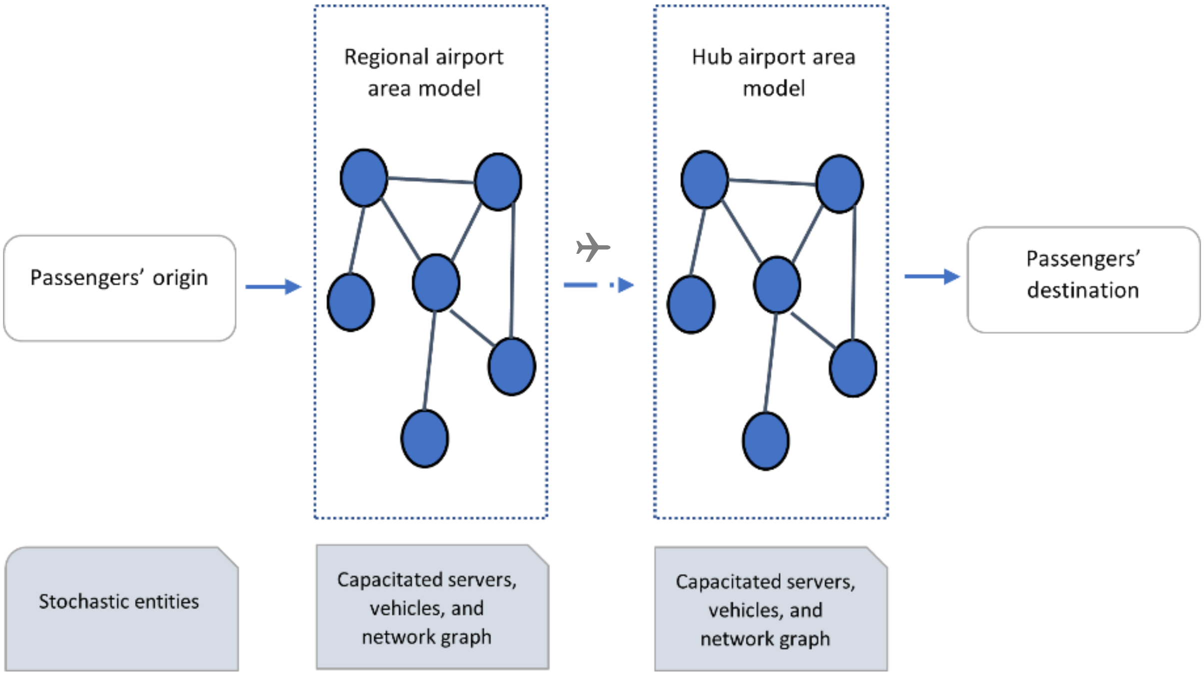


Figure 9. ConOps validation framework structure

There are three main groups of elements implemented in the model. The first group, dynamic entities, represents passengers and vehicles transporting passengers from their origin to the airport. The second group, static elements, represent transport stations the passengers use to embark/disembark on and off transport vehicles. These stations serve as the entry, transfer, and exit points between elements in the modelled system, with a fixed location for the interconnected multimodal transport networks and are modelled as capacitated servers. The third group is the set of nodes and weighted edges connected into a scaled network that vehicles and passengers use to move through the space between transport stations.

The model was built using GIS information from OpenStreetMap [23] so that the weighted edges consider the real scale under study. The main purpose is to model the movement of vehicles and passengers through the multimodal transport network in a realistic fashion. Owing to this, interactions of IT systems or management aspects of transport systems were not explicitly modelled in the CVSF.

Within the framework, the arrival of passengers and most transportation means was generated stochastically based on the project assumptions. Some transport means (such as buses and trains) were generated on a schedule, as observed in real-life operations. An overview of used assumptions is given in section 6.2.

4.4.1 Modelling D2A journey

A 2D view of the D2A model is shown in Figure 10. There are two parts in this model. The right part represents the origin town for passengers (Brunswick or Braunschweig), and the left represents the destination city which encompasses the regional airport (Hannover). These urban areas are located approximately 60 km from each other. For modelling purposes, the road and railway networks connecting these two areas were simplified into straight edges, simulating a total travel distance between two chosen points in each of the areas. For instance, for the railway, the "inter-city" edge connects Brunswick Central train station and Hannover Central train station. For the road network, the edge connects Hannover Airport Arrivals and Brunswick Highway 301 ring around the city.

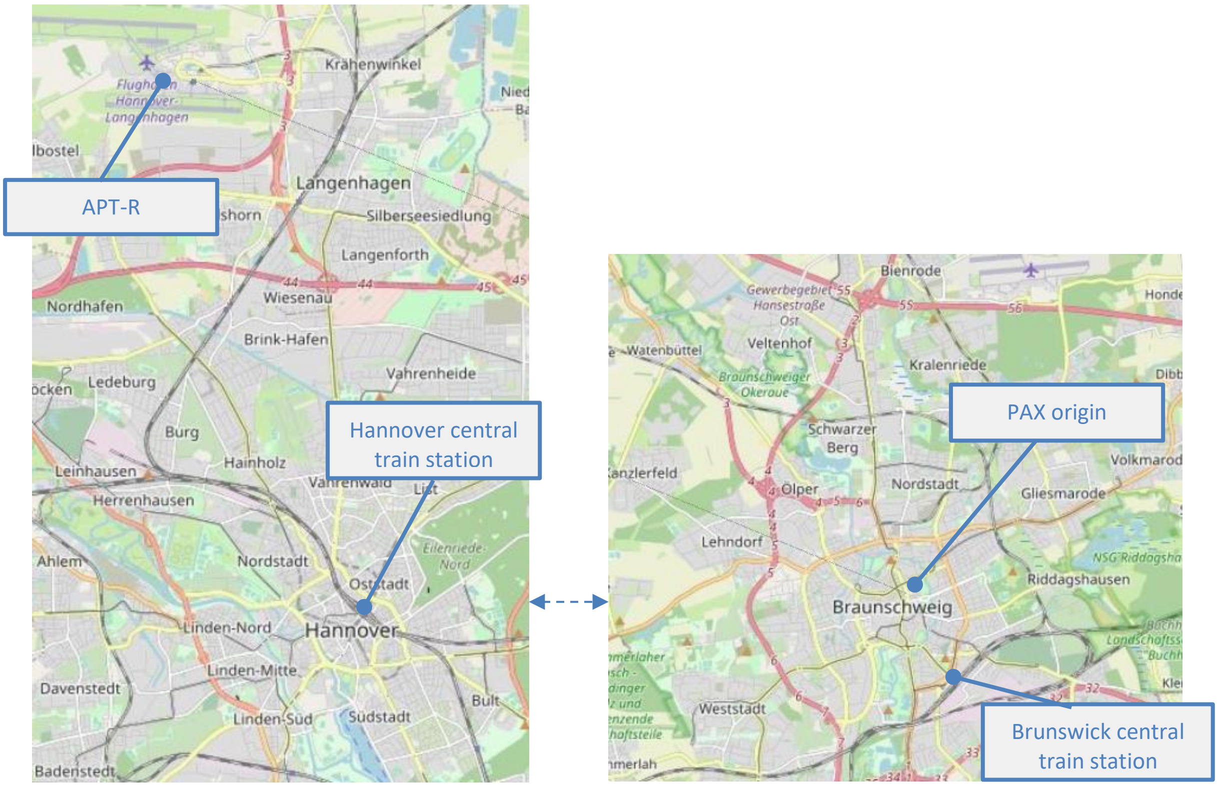


Figure 10. Regional airport area model (GIS layer) – D2A

The passenger journey was simulated in the way schematically presented in Figure 11. All 18 scenarios were simulated in the same way, with the different transport modes available at the corresponding time horizon in each scenario. The flowchart for the PAX journey in each experimental scenario can be found in Appendix A - Appendix C.

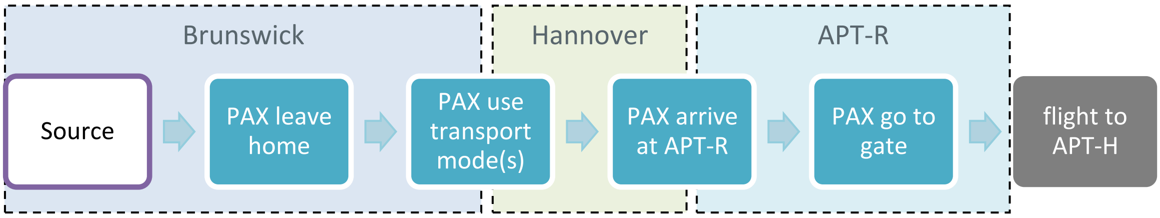


Figure 11. PAX journey in the D2A model

All passengers were stochastically generated in Brunswick at element "Source" considering relevant scenario assumptions. In this element, PAX group entities were created, and their properties, such as PAX profile, walking speed and group size, were set. Furthermore, in this element, each PAX entity got a label containing information about the entity creation's time and place.

After all initial PAX properties have been set in "Source", the PAX entity moved to the next step, which simulates PAX leaving their house and walking to the first transport mode station or PAX waiting at their doorstep for a transport vehicle to pick them up from their house. In this step, a random location of PAX origin was simulated. To simulate the random location of PAX origin within Brunswick, the PAX travelled distance on this part of the journey is adjusted by a random value as defined in the simulation assumptions in section 6.2.2. An example of such assumptions in the PAX journey is illustrated in Figure 12. The entire journey description can be found in Appendix A.

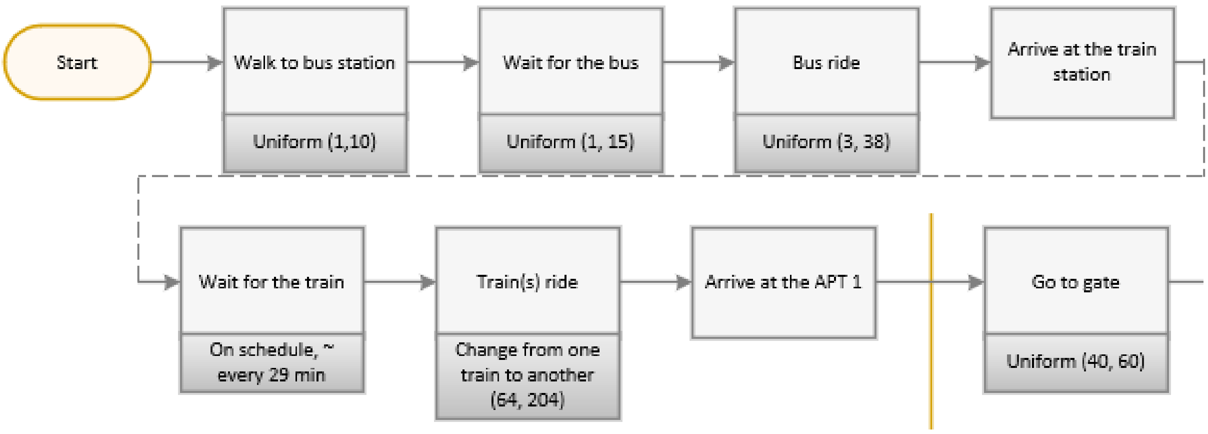


Figure 12. PAX journey from Brunswick to Hannover APT in D2A part in scenario B025

After that step, the PAX used buses, trains, or other transport modalities, corresponding to the scenario simulated to get from Brunswick to Hannover APT (APT-R element). In the APT-R element, the PAX was delayed simulating walking to the gate and various airport security procedures. After that, it could board an aircraft if the boarding to a flight to APT-H has been started. If not, the PAX was held at the APT-R until such boarding started. An example of corresponding flow and assumptions for the Business passenger in 2025 can be seen in Figure 13.

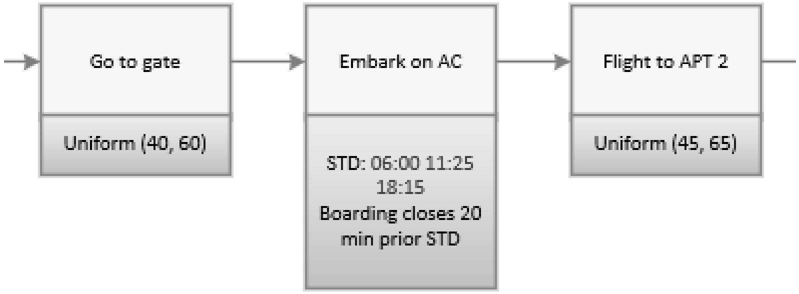


Figure 13. APT-R part of the D2A journey in scenario B025

After boarding the aircraft, the PAX was held until the flight departure time and then moved to the next model – A2D (PAX took the flight).

4.4.2 Modelling A2D journey

A 2D view of the A2D model is shown in Figure 14. The PAX's end destination city of Haarlem is located ten kilometres away from the hub airport of Schiphol, which made it possible to model the existing road and railway network directly on the GIS blueprint.

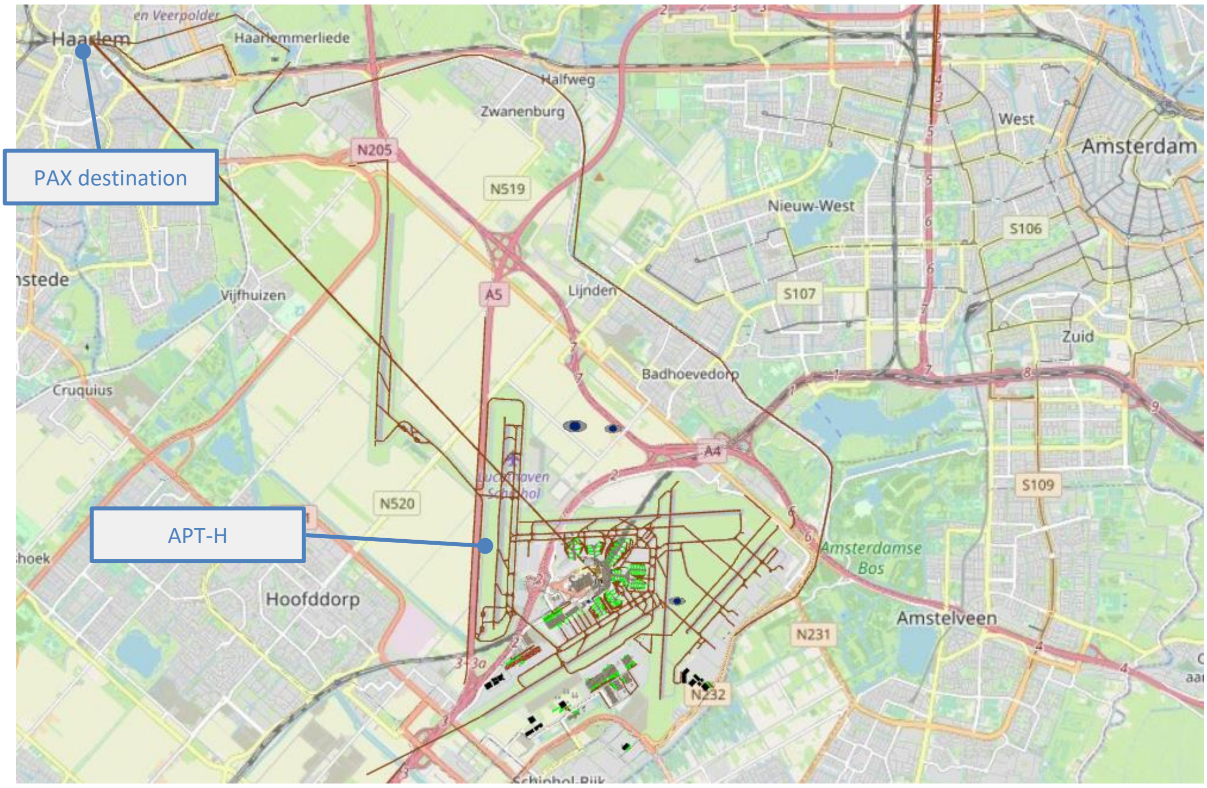


Figure 14. Hub airport area model (GIS layer) – A2D

In this A2D model, the passenger journey was simulated in the way schematically presented in Figure 15. All 18 scenarios were simulated similarly, with the different transport modes available for passenger use in each scenario.

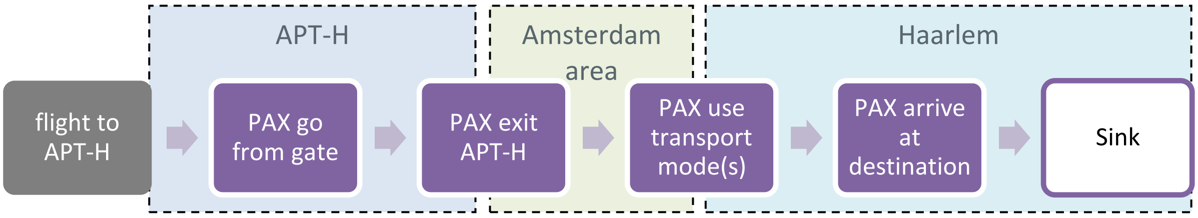


Figure 15. PAX journey in the A2D model

The journey continued when flight time finished, and the PAX entity moved from the D2A model into the A2D model. The PAX was delayed at the APT-H element until the time corresponding to walking from the gate, and the arrival procedures expired. An example of this phase for scenario B025 can be seen in Figure 16. After the delay time expired, the PAX entity moved to an access node for a transport modality defined by a specific experimental scenario.

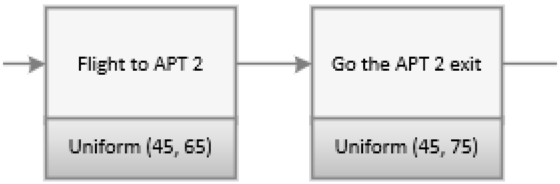


Figure 16. APT-H part of the A2D journey in scenario B025

As in the D2A model, in the A2D model, passengers used only the transportation modes considered in the specific experimental scenario. When the PAX entity used the scenario defined transport modes and reached the destination in Haarlem, it was moved to an element "Sink" for being destroyed from the simulation framework. In this element, the PAX statistics were also recorded and then the PAX entity was destroyed to keep the use of computational resources on the optimal level. This part of the journey is illustrated in Figure 17.

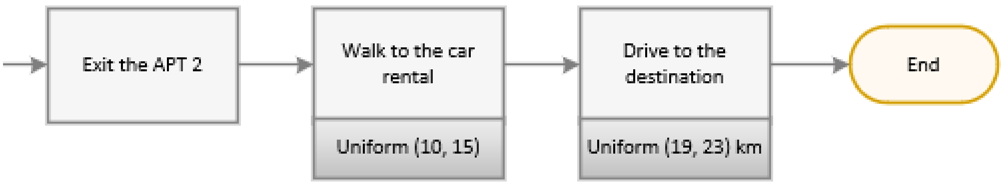


Figure 17. Amsterdam area and Haarlem part of the A2D journey in scenario B025

5 ConOps validation KPAs and KPIs

5.1 System performance KPIs

To judge the impact of ConOps on the multimodal travel experience, it is necessary to evaluate the efficiency and quality of the system elements. For this purpose, X-TEAM D2D defined several KPIs that can help analyse and compare different time horizons and different multimodal network setups. The summary of all considered KPIs is shown in Table 6.

KPA	KPI	Measurement	Comments
D2D journey efficiency	Total distance travelled	Door-to-door distance	per PAX
	Total travel time	Door-to-door time	per PAX
	Average travel speed	Total distance travelled / Total travel time	per PAX
D2D journey quality	Waiting time at interconnections	(Egress time – Access time)/ Total travel time	per PAX
	Probability of delays from breakdowns/maintenance	Total time of delay/total operating time (on a weekly/monthly base)	per operating line
	Accessibility of wayside infrastructures	Number of architectural barriers encountered /number of obstacles	per mode
	Luggage security	Lost and stolen probability	per PAX
	Ticketing user-friendliness	Mean time spent on ticketing	per PAX
System resilience	Response time to service interruptions	Average to restore the service/average	per operating line
Technology impact on D2D journey	Travel distance improvement	Average per scenario X/ average per scenario Y	Compare system performance across scenarios, time horizons
	Travel time improvement	Average per scenario X/ average per scenario Y	
D2D journey structure	Number of modes included in a single ticket	Number of tickets/number of modes	per ticket
	Number and modes used	Recording name of each mode used per PAX in D2D	per PAX
Cost	Total cost of travel	EURO/PAX	per PAX
Journey efficiency (from Provider's point of view)	Utilization Rate	Number of PAX/Vehicle	per Vehicle
	Cost on level of services provided	Based on amount of interconnection/ kind of vehicles used	per PAX
	Energy cost	Average energy required to operate each transport mode	per PAX or km

Table 6. Overview of all KPAs and KPIs relevant for ConOps validation

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Only the KPA "D2D journey efficiency" and KPI "Waiting time at interconnections" have been estimated in this validation report. Due to the level of abstraction of the research performed for this project, the rest of the defined KPIs could not be measured in the ConOps validation exercise, as they require a higher level of details than considered in X-TEAM D2D. Nevertheless, these KPIs are essential for quality measurement of the future more elaborated formulations of ConOps and therefore were listed in this section.

5.2 Passenger-focused KPIs

A system of performance indicators aims to evaluate the success of an organization or an activity with respect to the desired output in a given context [24]. In relation to the D2D multimodal journey passengers, Key Performances Indicators should represent the relevance (Key) for a specific type of passenger of one or more specific aspects of the D2D mobility service, with respect to his/her expectations and needs (performance) that can be quantitatively measured (Indicator). In addition, within the X-TEAM D2D framework, we should consider that KPIs should be carefully selected to either be applicable at the abstraction level set for the simulation or provide useful information [25]. This is particularly relevant for the passenger-centric and stepwise approach of X-TEAM D2D because it is acknowledged that performance measurement and monitoring significantly impact the development, implementation and management of existing transport plans and programmes and largely contribute to the identification and assessment of successful alternative scenarios. Then, the consideration of specific passenger related KPIs paves the way to the comparison, under the passengers' point of view, of different projects and programmes in future scenarios and to evaluate the performance of the same project and system at different time points [26]. When defining passenger related KPIs, the following aspects should be taken into account [26]:

- satisfaction of the transport service user, in addition to the concerns of the system operator or owner
- societal concerns such as traffic efficiency, traffic safety, environmental conservation, social inclusion
- available resources and tools for measurements; this means that performance measures should be measurable with tools and resources available, costs should be reasonable with respect to the budget, accuracy levels should be comparable with respect to requirements, data should be retrievable through field measurement
- possibility to compare future alternative scenarios and to use existing forecasting tools for its definition
- understandability by policy makers, professionals, and the general public
- direct measure of the issue of concern or at least maximum relevance or meaningfulness
- the entirety of means, legs, and steps of the multimodal journey
- performance measures should allow to control and improve the measured characteristic; they should provide decision-makers with relevant information for their decision-making processes.

In addition to the above-listed characteristics, it could be considered that passenger related KPIs fall under the social dimension of sustainability KPIs. Combining the passenger-centred perspective defined in the X-TEAM D2D project [18], the passenger-centred requirements defined within X-TEAM D2D, passenger-focused KPI should address the following performance areas [25], [27]: Safety, Health, Travel time, Accessibility, Affordability, Reachability, Participation. Table 7 recaps the Passenger-focused KPIs proposed in the scope of the X-TEAM D2D project.

KPI	Relevance per passenger profile	Direction	Data Availability
Total travel time	BT ○○○ VFRT ○	Less time is better	usually available in standardized form
Waiting time at interconnections	BT ○○○ VFRT ○○	Less time is better	usually available in standardized form
Frequency (probability) of delays from breakdowns/maintenance etc	BT ○○○ VFRT○○	Less probability is better	possibly available but not standardized
Accessibility of wayside infrastructures	BT ○○ VFRT○○○	Less barriers is better	requires specific data collection
Luggage security	BT ○ VFRT○○○	Less loss and stolen probability is better	requires specific data collection
Ticketing user-friendliness	BT ○ VFRT○○○	Less time spent for ticketing is better	requires specific data collection
Response time to service interruptions	BT ○○○ VFRT ○○	Less time to recover is better	usually available in standardized form
Travel time reduction	BT ○○ VFRT○○	More reduction is better	usually available in standardized form
Number of modes included in a single ticket	BT ○ VFRT ○○○	More is better	usually available in standardized form
Number and modes used	BT ○○○ VFRT ○○○	Less is better (or more alternatives available is better)	possibly available but not standardized
Total cost of travel	BT ○○ VFRT ○○○	Less is better	usually available in standardized form

Table 7. KPIs' relevance per passengers' profiles

6 ConOps validation exercise

To validate the ConOps, a series of validation experiments has been run in the simulation framework developed in WP5 and described in section 4.4. Each experiment simulated a passenger journey through a multimodal transportation system, according to the use cases and scenarios introduced in section 6.1.

The workflow applied in the ConOps validation study is shown in Figure 18. The CVSF used as input for each experiment the values of the corresponding assumptions for transport modes and passengers (use cases). Each simulation experiment run was executed in the CVSF for 24 hours of simulation time with 50 replications to obtain statistically relevant results [28].

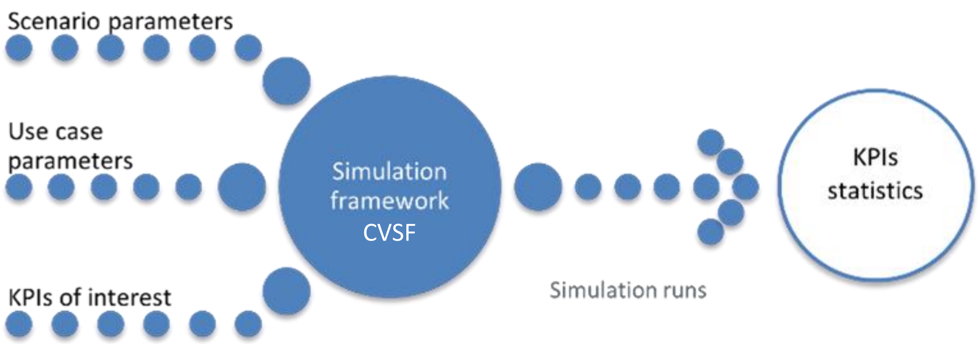


Figure 18. Experimental workflow for ConOps validation

For each experiment, the PAX KPIs noted in Table 6 were recorded in a CSV file, separate for each scenario. A partial screenshot of the raw data obtained in such a way for scenario B025 is shown in Figure 19.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Destination	TimeTripEnded	NrPAXentered	TimeTripStarted	ModesUsedL1	TotalDistanceL1	APT1	APT2	ModesUsedL2	TotalDistanceL2	PAXtype	TotalWaitingTime	Scenario	PAXdemotype
2	SinkD_Haarlem	14/10/2021 13:35	1	14/10/2021 07:09	w,bu,train,train,air	84377.08	14/10/2021 09:46	14/10/2021 13:12	c	21678.06739	B	0.225081783	25	< 65
3	SinkD_Haarlem	14/10/2021 13:35	1	14/10/2021 06:36	w,bu,train,train,air	78662.33	14/10/2021 09:46	14/10/2021 13:12	c	20421.56499	B	1.110607035	25	< 65
4	SinkD_Haarlem	14/10/2021 13:37	1	14/10/2021 06:52	w,bu,train,train,air	85765.28	14/10/2021 09:45	14/10/2021 13:14	c	20171.60498	B	0.332323213	25	< 65
5	SinkD_Haarlem	14/10/2021 13:37	1	14/10/2021 06:52	w,bu,train,train,air	78750.92	14/10/2021 09:46	14/10/2021 13:12	c	20857.30526	B	0.92236368	25	< 65
6	SinkD_Haarlem	14/10/2021 13:37	1	14/10/2021 06:52	w,bu,train,train,air	78282.16	14/10/2021 09:38	14/10/2021 13:12	c	20801.36154	B	0.838695182	25	< 65
7	SinkD_Haarlem	14/10/2021 13:38	1	14/10/2021 06:11	w,bu,train,train,air	78407.48	14/10/2021 08:42	14/10/2021 13:14	c	20518.40663	B	0.5347828	25	< 65
8	SinkD_Haarlem	14/10/2021 13:40	1	14/10/2021 08:03	w,bu,train,train,air	78672.16	14/10/2021 10:39	14/10/2021 13:16	c	20176.74364	B	0.72171271	25	< 65
9	SinkD_Haarlem	14/10/2021 13:40	1	14/10/2021 05:00	w,bu,train,train,air	82067.32	14/10/2021 07:36	14/10/2021 13:15	c	19920.19774	B	0.488585411	25	< 65
10	SinkD_Haarlem	14/10/2021 13:40	1	14/10/2021 07:09	w,bu,train,train,air	82501.50	14/10/2021 09:49	14/10/2021 13:16	c	20225.52289	B	0.358687635	25	< 65
11	SinkD_Haarlem	14/10/2021 13:40	1	14/10/2021 06:40	w,bu,train,train,air	83086.42	14/10/2021 09:48	14/10/2021 13:17	c	20687.96393	B	0.791584687	25	< 65

Figure 19. Example of raw data obtained for scenario B025

6.1 Experimental scenarios

In each considered time horizon, business and VFR passengers use various transport modes. Depending on the type of scenario (normal, ad-hoc disturbance or disturbance five hours prior to the departure), some modes change their availability for use by passengers. The detailed description of passengers' journey for each scenario can be found in WP2 deliverable D2.1 "Future Reference Scenarios and Barriers".

Within the scope of the ConOps validation study, two groups with nine scenarios each have been defined to represent the D2D journey of business and VFR passengers in 2025, 2035, and 2050, as depicted in Figure 20. Each experimental scenario simulated 24 hours of passengers travelling from a small European town to a large metropolitan area in a different European country. During this journey, passengers used only transport modes described in the corresponding scenario. Each mode operated according to the assumptions listed in section 6.2.

Time horizon	2025		2035		2050	
	Traveller		Traveller		Traveller	
Disturbance	Profile B	Profile V	Profile B	Profile V	Profile B	Profile V
no disturbance	B025	V025	B035	V035	B050	V050
5h prior to departure	B525	V525	B535	V535	B550	V550
ad hoc disturbance	Bd25	Vd25	Bd35	Vd35	Bd50	Vd50

B: Business traveller   V: VFR - Visiting friends and relatives traveller

Figure 20. Overview of ConOps validation scenarios.

Profile B - A business traveller makes a one-day trip from an origin area with a regional airport to a destination area with a hub airport.

Profile V - Use cases for this group of VFR include two adults (one of whom is a senior) and a minor child with baggage visiting friends and relatives for a long weekend at a family event (e.g., a wedding).

Each scenario was simulated in 50 replications to capture the D2D system behaviour better. The results of these experiments are discussed in section 7.3.

6.1.1 Scenarios for 2025

A multimodal journey - if taken for the first time - has to be planned in advance and managed by the traveller himself/herself. Planning can be done with the use of online services provided. Online: Ability to buy tickets in advance, check-in at least the day before flight, remote ticket validation systems. Flight is booked via a Travel agency, app, or internet in advance.

6.1.1.1 B025 – no disturbance

- Traveller starts at home.
- Using the combination bus and train to the regional airport. Ticket purchased via mobile app/online.
- Arrival at the regional airport (no registered luggage, passenger checked online the day before): He/she walks to the gate. Time spent waiting during the multimodal journey is significant: e.g., passengers must be at the gate at least 30 minutes before take-off.
- Flight (with an aircraft; digital ticket purchased online).
- Arrival at hub airport: There is no direct access to e-bikes, e-scooters sharing system. Getting car-sharing or rental cars services requires a longer walk distance.
- Traveller takes a rental car from the airport to business address.
- Traveller arrives at a business address.

6.1.1.2 B525 - disturbance 5h prior to departure

There is disturbance **information** five hours before the start of the planned trip. Disturbance: technical failure on the train track.

- Traveller starts at home: He/she finds out about the delay of the train via e-mail/app information service before leaving his/her home. The traveller has to manage the new planning of the journey by him/herself.
- Traveller can order an e-taxi via app or use car-sharing to catch up with his former plan to reach the airport in time (Assistance of the travel agency of his company could help to change the booking of his flight).
- Traveller walks to a car-sharing depot and uses an autonomous car to the airport (the single ticket purchased in advance is still valid).
- Traveller arrives at the regional airport and leaves the car in the car-sharing parking slot.
- He/she uses New Mobility Services (e.g., e-scooters) at the airport parking to reach his/her terminal in time.
- Flight (with an aircraft; digital ticket purchased online).
- Arrival at hub airport: There is no direct access to e-bikes and e-scooters sharing system. Also, getting car-sharing or rental cars services requires a longer walking distance.
- Traveller takes a rental car from the airport to business address.
- Traveller arrives at a business address.

6.1.1.3 Bd25 - disturbance ad hoc

A business traveller is making a one-day trip from an origin area with a regional airport to a destination area with a hub airport. Digital tickets are purchased via a Travel agency, app or internet in advance. During the trip, a disruption occurs in one of the transport modes.

- Business traveller starts at home.
- He/she uses the bus to the train station.
- Traveller arrives at a train station. While waiting for the train, the traveller receives the information of a disruption: technical failure on the track (Train is late/cancelled). The traveller must manage the new planning of his journey by himself/herself via a portable device (smartphone). Calls a taxi via telephone or app to reach the planned flight.
- Takes a taxi to the regional airport using an app to call and pay for the ride.
- Arrival at the airport (no registered luggage, passenger checked in during the morning). Uses a fast track through security to catch up on delay (if available and possible: Traveller needs to persuade the security staff to use the fast track). Or misses the flight and needs to change the flight: Getting assistance from the travel agency of the traveller's company via phone or change the booking directly via airline app or online.
- Flight (digital ticket purchased via a Travel agency, app or internet).
- Arrival at hub airport: The traveller takes an e-taxi from the airport taxi stand directly to the business address. During the taxi trip, the traveller cancels the car-sharing/Rental car booking.
- Traveller arrives at a business address.

6.1.1.4 V025 - no disturbance

- travellers start at home: Multimodal journeys must be planned in advance and to be managed by the travellers themselves. The trip will be planned within a buffer of 1 to 2h at the beginning

of the journey to reach the airport in time and at least 1 to 2 days before the event (e.g., wedding) for unexpected complications;
- planning can be done with the use of online services provided. Ability to buy tickets in advance, proceed to check-in at least the day before the flight, remote ticket validation systems. Flight is booked via a Travel agency, app or internet in advance;
- using the combination of busses/trains to reach the regional airport because the change from one mode to the other is comfortable (digital group ticket purchased);
- arrival at the airport (registered luggage, passenger checked online the day before): They have to go to check-in with their luggage and then through security and to the gate. Time spent waiting during the multimodal journey is significant: The group have to be at the gate at least 30 minutes before take-of, time
- needed for reaching the gate in hub airport is about 25 minutes and 15 in case of the regional airport and takes even longer with minors;
- flight (with an aircraft; digital group ticket purchased);
- arrival at hub airport: They need to walk through customs to the airport train or bus terminal;
- using the combination busses/trains of the public service, because the change from one mode to the other is comfortable (ticket purchased online via mobile app/online);
- travellers reach the accommodation.

6.1.1.5 V525 - disturbance 5h prior to departure

Use cases for this group of VFR include two adults (one of whom is a senior) and a minor child with baggage visiting friends and relatives for a long weekend on the occasion of a family event (e.g. wedding). There is disturbance information before the start of the planned trip.

- travellers are at home: Multimodal journey has to be planned in advance and to be managed by the travellers themselves. The trip will be planned within a buffer of 1 to 2h at the beginning of the journey to reach the airport in time and at least 1 to 2 days before the event (e.g. wedding) for unexpected complications;
- planning can be done with the use of online services provided. Online: Ability to buy tickets in advance, proceed to check-in at least the day before the flight, remote ticket validation systems. Flight is booked via a Travel agency, app or internet in advance;
- the travellers find out about the delay/cancellation of the planned train via e-mail/app information service before leaving his/her home (Disruption: Technical failures on the train track). The travellers have to manage the new planning of their journey by themselves;
- the travellers use a different combination of busses and trains to the regional airport (with longer travelling time), but they reach the airport and the flight in time because they were 1-2 hours early. Eventually, they need to purchase a new ticket for this routing because it’s not the direct way to the airport (digital group ticket purchased);
- arrival at the airport (registered luggage, passenger checked online the day before): They have to go to check-in with their luggage and then through security to the gate. Time spent waiting during the multimodal journey is significant: The group have to be at the gate at least 30 minutes before take-off; the time needed for reaching the gate at the hub airport is about 25 minutes and 15 in case of the regional airport and takes even longer with children;
- flight (with an aircraft; digital group ticket purchased);
- arrival at hub airport: They need to walk through customs to the airport train or bus terminal;
- using a combination of busses and trains (group ticket purchased online via mobile app/online);
- travellers reach the accommodation.

6.1.1.6 Vd25 - disturbance ad hoc

Use cases for this group of VFR include two adults (one of whom is a senior) and a minor child with baggage visiting friends and relatives for a long weekend on the occasion of a family event (e.g. wedding). During the trip, a disruption occurs in a mode of transport.

- travellers start at home: Multimodal journey has to be planned in advance and to be managed by the travellers themselves. The trip will be planned within a buffer of 1 to 2h at the beginning of the journey to reach the airport in time and at least 1 to 2 days before the event (e.g. wedding) for unexpected complications;
- planning can be done with the use of online services provided. Online: Ability to buy tickets in advance, proceed to check-in at least the day before the flight, remote ticket validation systems. Flight is booked via a Travel agency, app or internet in advance: They want to use a combination of public busses/trains to reach the regional airport because the change from one mode to the other is comfortable (ticket purchased online via mobile app/online);
- they use the bus to the train station (digital group ticket purchased);
- when they arrive at the train station, there is disturbance information for a train on the planned journey (Disruption: Technical failures on the train track). The travellers have to manage re- planning of their journey by themselves;
- the travellers using a different combination of busses and trains to the regional airport (with extended travelling time). Eventually, they need to purchase a new ticket (or upgrade to the old ticket) for this routing because it’s not the direct way to the airport (online via mobile app/online);
- during this new routing, the travellers call the airport in Advance: For disabled passengers and passengers with reduced mobility (PRM) the airport operator is responsible for providing assistance to these passengers to be able to get into and off the aircraft (Regulation (EC) No. 1107/2006 EU);
- arrival at the regional airport is much later than expected (registered luggage, passenger checked online the day before): They walk to the check-in and got from there a with an electric cart with driver for PRM by the airport operator and got a quick and safe transfer through security to their gate;
- flight (with an aircraft; tickets purchased in advance online);
- arrival at hub airport: They are walk through customs to the airport train or bus terminal (or get another ride with an electric cart for PRM by the airport operator through customs, baggage claim to the airport train/bus station);
- using the combination busses/trains of the public service (ticket purchased online via mobile app/online);
- travellers reach the accommodation.

6.1.2 Scenarios for 2035

Exchange of information between ATM and surface modes, together with access and communication with the user’s portable device, allows providing the travellers with all data concerning his/her multimodal journey in advance (at least a day before the day of the journey). The traveller will be provided with available alternatives allowing the traveller to react in time (with respect to his requirements, e.g., related to disabilities). Privately generated data will be available for service providers daily demand forecasts will become possible, making the transport system more efficient and sustainable. The traveller got the possibility to modify his/her journey a day before travel (select other modes according to his preferences). Traveller will be offered to purchase one single ticket for entire journey with access rights to change modes. Check-in is done automatically at the start of the journey (check-in at the first hub of the journey). Due to technology development, more users' focus will be on personal needs as well as the impact on the environment.

6.1.2.1 B035 - no disturbance

- Traveller starts at home.
- Walks to a e-scooter/e-bike sharing depot and uses a e-scooter to eVTOL platform (covered by the single ticket (devices) for the journey. Not completed digitalization of transport systems will prevent including all modes of transport in this solution).
- Takes eVTOL flight to the regional airport (single ticket online using a mobile app). Incomplete digitalization of transport systems will prevent including all modes of transport in this solution.
- Arrival at the regional airport (no registered luggage, passenger checked-in automatically in the first node). Uses an e-scooter: Time spent to reach the gate will be slightly reduced.
- Flight by a short-range aircraft.
- Arrival at a hub airport. There is no direct access to e-bikes, e-scooters sharing systems. Electric taxis are partially replaced by electric car-sharing and are easier accessed from the airport terminal.
- Traveller takes electric car-sharing from airport to business address (included in the single ticket booked in advance).
- Traveller arrives at a business address.

6.1.2.2 B535 - disturbance 5h prior to departure

A business traveller making a one-day trip from an origin area with a regional airport to a destination area with a hub airport. There is a disturbance before starting the planned trip. Traveller modified his/her journey a day before travel (select other modes according to their preferences). Traveller purchased one single ticket for the entire journey with access rights to change nodes. Increased reliability of transport will allow for less care needed for alternative connections considerations (in case of **disruption**). Disruptions will be less frequent, and the time for recovery will be reduced thanks to using of resources of other integrated modes not affected by the disruption. Privately generated data will be available for service providers daily demand forecasts will become possible, making the transport system more efficient and sustainable.

ATM Information of disturbance (e.g., harsh weather conditions) of the planned e-VTOL flight is available for the traveller before his/her starts the journey. The traveller is provided with available alternatives modes (e.g., e-taxi, e-car-sharing, and train) by an upcoming disruption allowing traveller to react in time (with respect to his requirements, e.g., related to disabilities). In case of lack of alternative) the traveller will have to manage disruption completely by his/herself with the use of a mobile application providing data gathered from transport operators (more common in peri-urban locations).

- Traveller starts at home.
- Disruption. The weather conditions interact with the other planned traffic modes, too. Rebooks the planned e-scooter/e-bike ride to autonomous e-car drive with car-sharing.
- Traveller walks to a car-sharing depot and uses a car to the train station (the single ticket purchased in advance is still valid). Leaves car at the car-sharing parking.
- Uses train to the airport.
- Arrival at the airport (no registered luggage, passenger checked-in automatically in the first node). Time spent on changing nodes will be slightly reduced, especially off the traffic peak.

- Flight by a short-range aircraft (included in purchased single ticket in his/her device).
- Arrival at hub airport. There is no direct access to e-bikes, e-scooters sharing system. Electric taxis are partially replaced by electric car-sharing and are easier accessed from the airport terminal (replaced “traditional” rental cars).
- Traveller takes electric car-sharing from airport to business address (included in the single ticket book in advance).
- Traveller arrives at a business address.

6.1.2.3 Bd35 - disturbance ad hoc

Traveller modified his/her journey a day before travel (select other modes according to his preferences). Traveller purchased one single ticket for the entire journey with access rights to particular change nodes. The planned modes are integrated with ATM: Information about disruptions (e.g., delay) will be available for the traveller in a very short time, and if necessary, the traveller will be provided with available alternatives (in respect to his requirements, e.g., related with disabilities). This allows the traveller to react in time. In case of lack of alternatives, the traveller will have to manage disruption by his/herself with the use of a traditional mobile application providing data gathered from transport operators (more common in peri-urban locations). Privately generated data will be available for service providers daily demand forecasts will become possible, making the transport system more efficient and sustainable. Due to technology development, more users’ focus will be on personal needs as well as the impact on the environment. During the journey, a disruption occurs in a mode of transport.

- Traveller starts at home. Walks to a e-scooter/e-bike sharing depot and uses a e-scooter to e-VTOL platform (buying a single ticket via devices in advance). There is an ATM Information of disturbance of the planned e-VTOL flight (e.g., delay because of harsh weather conditions). The disruption endangers the timely departure of the aircraft, the passenger is offered to use a taxi (co-financed by the operator).
- Traveller is picked up by e-taxi and brought to the airport.
- Arrival at the airport. Check-in is done automatically at the start of the journey (check-in at the first hub of the journey). The traveller is guided to a fast-track through security to catch his/her regular flight in time (no registered luggage).
- Flight by a short-range aircraft (included in purchased single ticket in his/her device).
- Arrival at a hub airport. There is no direct access to e-bikes, e-scooters sharing system. Electric taxis are partially replaced by electric car-sharing and are easier to access from the airport terminal (replaced “traditional” rental cars).
- Traveller takes electric car-sharing from hub airport to business address (included in the single ticket booked in advance).
- Traveller arrives at a business address.

6.1.2.4 V035 - no disturbance

Travellers got the possibility to modify their journey a day before travel (select other modes according to his preferences). Travellers will be offered to purchase a group ticket for the entire journey with access rights to particular change nodes. Due to technology development, more users’ focus will be on personal needs as well as the impact on the environment. Check-in is done automatically at the start of the journey (check-in at the first hub of the journey).

The exchange of information between ATM and surface modes, together with access and communication with the user’s portable device, allows for providing travellers with all data concerning their multimodal journey in advance. The travellers will be provided with available alternatives allowing traveller to react in time (with respect to their requirements, e.g., related to disabilities). Privately generated data will be available for service providers daily demand forecasts will become possible, making the 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.

- Travellers start at home. VFR traveller groups use various combinations of public transport according to their preference to reach the regional airport (digital group ticket purchased). Time spent on changing nodes will be slightly reduced because of the exchange of information between ATM and surface modes.
- Arrival at the airport (registered luggage, check-in at the first hub of the journey): VFR travel group with seniors is automatically picked up at the train/bus terminal by the airport operator (PRM) with an autonomous electric cart. They will be taken to the check-in to check-in their luggage. Then they will be brought through security to their gate. Time spent waiting will be slightly reduced. The time needed for reaching the gate at the regional airport will be less than 5 minutes.
- Flight (with a short-range aircraft).
- Arrival at hub airport: They got another ride with an autonomous electric cart for PRM by the airport operator through customs and baggage claims to the airport train/bus station).
- Use various combinations of public transport according to their preference (group tickets purchased online via mobile app/online).
- Travellers reach the accommodation.

6.1.2.5 V535 - disturbance 5h prior to departure

There is a disturbance before starting the planned trip. Travellers got the possibility to modify their journey a day before travel (select other modes according to their preferences). Travellers will purchase a group ticket for the entire journey with access rights to particular change nodes. Due to technology development, more users' focus will be on personal needs as well as the impact on the environment. Check-in is done automatically at the start of the journey (check-in at the first hub of the journey).

The exchange of information between ATM and surface modes, together with access and communication with the user's portable device, allows for providing travellers with all data concerning their multimodal journey in advance. The travellers will be provided with available alternatives allowing traveller to react in time (with respect to their requirements, e.g., related to disabilities). Privately generated data will be available for service providers daily demand forecasts will become possible, making the transport system more efficient and sustainable. This development means no buffer is needed at the beginning of the journey to reach the airport in time.

- Travellers are still at home. ATM Information about disturbances (e.g., harsh weather conditions) of flights and train connections to the airport is available for the travellers before their journey starts. Travellers are provided with available alternatives modes (e.g., e-taxi, e-car-sharing) by an upcoming disruption allowing traveller to react in time (in respect to his requirements, e.g., related to disabilities). In case of lack of alternative travellers will have to manage disruptions completely by themselves with the use of a mobile application providing data gathered from transport operators (more common in peri-urban locations).
- Travellers order autonomous transport by car-sharing via the internet and use the car to get to the regional airport (Group card purchased in advance for public service will be credited).

Co-funded by the European Union

- Arrival at the airport (registered luggage, check-in at the first hub of the journey). Leaving car at the car-sharing parking. VFR travel group with seniors is automatically picked up at the car-sharing parking next to their car by the airport operator (PRM) with an autonomous electric cart. They will be taken to the check-in to check-in their luggage. Then they will be brought through security to their gate. Time spent waiting will be slightly reduced. The time needed for reaching the gate at the regional airport will be less than 5 minutes.
- Flight (with a short-range aircraft).
- Arrival at hub airport: They got another ride with an autonomous electric cart for PRM by the airport operator through customs (and baggage claims) to the airport public transport station.
- Using combinations of public buses and trains according to their preference (group tickets purchased online via mobile app/online).
- Travellers reach the accommodation.

6.1.2.6 Vd35 - disturbance ad hoc

During the trip, a disruption occurs in a mode of transport. Travellers got the possibility to modify their journey a day before travel (select other modes according to their preferences). Travellers will purchase a group ticket for the entire journey with access rights to particular change nodes. Due to technology development, more users' focus will be on personal needs as well as the impact on the environment. Check-in is done automatically at the start of the journey (check-in at the first hub of the journey).

The exchange of information between ATM and surface modes, together with access and communication with user's portable device, allows for providing travellers with all data concerning their multimodal journey in advance. The travellers will be provided with available alternatives allowing traveller to react in time (with respect to his requirements, e.g., related to disabilities). Privately generated data will be available for service providers daily demand forecasts will become possible, making transport system more efficient and sustainable. This development means no buffer is needed at the beginning of the journey to reach the airport in time.

- Travellers start at home. VFR travellers use the bus to the train station (digital group ticket purchased). During the lift the travellers receive information about a disruption (e.g., Harsh weather conditions) which is affecting their upcoming train ride to the airport. They are provided with available alternatives modes. Travellers order autonomous transport by car-sharing via the internet and change their routing to a car-sharing depot: and use the autonomous car to the regional airport (Group card purchased in advance for public service will be credited).
- Late arrival at the airport (registered luggage, check-in at the first hub of the journey). Leaving the car at the car-sharing parking. VFR travel group with senior (PRM) is automatically picked up at the car-sharing parking next to their car by the airport operator with an autonomous electric cart. They will be taken to the check-in to check-in their luggage. Then they are automatically taken in the fast lane through security to their gate (full information about their delay status). The time taken to reach the gate at the regional airport will be less than 2 minutes.
- Flight (with a short-range aircraft).
- Arrival at a hub airport. They got another ride with an autonomous electric cart for PRM by the airport operator through customs (and baggage claims) to the airport public transport station.

- Using various combinations of public transport according to their preference (group ticket purchased online via mobile app/online).
- Travellers reach the accommodation.

6.1.3 Scenarios for 2050

Traveller is provided with all data concerning his/her multimodal journey at least every hour during the journey. He/she will have a possibility to modify his/her journey even on a day of journey (select other modes according to his preferences). Traveller purchases one single ticket for the entire journey with access rights to particular change nodes. The offer will be designed on the base of smart pricing favouring preferred/prioritised modes of transport (with regards to applied policies like carbon footprint or 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 the total system approach applied (System of Systems management). Completed digitalization will allow traveller to make transport mode more fitted to their individual preferences/needs: Next door is an NMS service including e-bikes/e-scooters and an electric autonomous car-sharing depot.

6.1.3.1 B050 - no disturbance

- Traveller starts at home.
- Traveller uses NMS to go to the next Urban Air Mobility (UAM) port.
- Traveller uses a UAM. For the Regional range, air travel will also be possible with the use of VTOL, multirotor and fixed-wing aircraft.
- Arrival at the regional airport (no registered luggage, the passenger was checked in automatically). Use of a UAM gives the traveller direct access to the regional airport. Security checks and check-in are already done with/during the use of the UAM.
- Traveller uses NMS services (e.g., e-bikes or e-scooters) at the airport. Passenger is in nearly no time at the gate.
- Flight with zero-emission large aircraft.
- Arrival at hub airport: NMS services (including e-bikes or e-scooters-versions) are commonly used in airports. There are (electric) micromobility (soft) means of transport to take the traveller to the high-speed rail transport station.
- High-speed rail transport ride. Traveller modifies his/her journey to his preferences (he/she likes boat tours) and selects a ride with an autonomous ferry service instead of surface planned traffic modes: CCAM.
- Arrival at the high-speed rail transport station with easy transfer to the water mode system of the destination city. The destination city is divided by large water reservoirs. Traveller uses an autonomous ferry service instead of surface planned traffic modes.
- Arrival at the ferry pier. He/she uses micromobility (soft) means of transport to the business address.
- Traveller arrives at a business address.

6.1.3.2 B550 - disturbance 5h prior to departure and Bd50 - disturbance ad hoc

Traveller is provided with all data concerning his/her multimodal journey at least every hour during the journey. He/she will have possibility to modify his/her journey even in a day of journey (select 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 on base of smart pricing favouring preferred modes of transport (with regards to applied policy like carbon footprint or emissions, sustainability level). Solutions will cover all or almost all publicly available means of transport. Time spent on changing nodes will be reduced thank to total system approach applied (System of Systems management). Completed digitalization will allow traveller to make transport mode more fitted to his individual preferences/needs: Next door is an NMS services including e-bikes/e-scooters and an electric autonomous car sharing depot.

There is an incident that leads to an interruption of the journey. In 2050 there is no difference for the traveller between disruptions information from 5h prior and during the journey. In case of disruption information about it will be available immediately and if it is necessary the traveller will be provided with required actions on his/her side. The traveller will have possibility to modify his/her journey even in a day of journey and select other modes according to his preferences/needs.

Disturbances in 2050 resulted with internal reason like failure or accidents originated outside the system will be very rare. The time for recovery will be extremely short due to using immediate activation of resources of other modes of transport.

- Traveller starts at home.
- Traveller uses NMS to go to the next Urban Air Mobility (UAM) port.
- Traveller uses an 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 (no registered luggage, passenger was checked in automatically). Use of an UAM gives the traveller a direct access to regional city airport. Security check and check-in is already done with/during the use of the UAM.
- Traveller uses NMS services (e.g., e-bikes or e-scooters) at airport. Passenger is in nearly no time at gate.
- Flight with zero-emission large aircraft. Shortly before landing at the hub airport the traveller reached a disturbance information about his/her high-speed train: Medical emergency on the booked high-speed train service. Heavy delay is possible. Traveller is given an alternative (UAM) to arrive safely on time for his appointment.
- Arrival at hub airport: There are (electric) micromobility (soft) means of transport to take the traveller through customs to airport UAM port.
- Traveller using an UAM. For the Regional range air travels, it's a fixed wing aircraft (digital ticket needs an upgrade payment);
- Landing at UAM port next to the business centre. With soft mode he/she is transported to the business address.
- Traveller arrives at business address.

6.1.3.3 V050 - no disturbance

Travellers are provided with all data concerning their multimodal journey at least every hour during the journey. They will have possibility to modify their journey even in a day of journey (select other modes according to his preferences). Travellers purchase a group ticket for entire journey with access rights to particular change nodes. The offer will be designed on base of smart pricing favouring preferred/prioritized modes of transport (with regards to applied policy like carbon footprint or emissions, sustainability level). Solutions will cover all or almost all publicly available means of transport. Time spent on changing nodes will be reduced thank to total system approach applied (System of Systems management). Completed digitalization will allow travellers to make transport mode more fitted to his individual preferences/needs. Luggage is delivered door-to-door.

- Luggage picked up in short notice before VFR traveller group starts at home.

- VFR traveller group starts at home. They are using NMS to go to the high-speed train station.
- Traveller uses high-speed train (digital group ticket purchased shortly before).
- Arrival at the regional airport (passengers were checked in automatically).
- Traveller uses micromobility means of transport at the airport. Passenger is in nearly no time at the gate.
- Flight with zero-emission large aircraft.
- Arrival at a hub airport. There are (electric) micromobility means of transport to take the traveller group through the customs to the high-speed rail transport station.
- High-speed rail transport ride. Traveller group modifies their journey to their preferences (e.g., they like boat tours) and select a ride with an autonomous ferry service instead of surface planned traffic modes: CCAM.
- Arrival at the high-speed rail transport station with easy transfer to the water mode system of the destination city. The destination city is divided by large water reservoirs. Travellers use an autonomous ferry service instead of surface planned traffic modes.
- Arrival at ferry pier next to their accommodation: They are using micromobility means of transport to the accommodation.
- Travellers reach the accommodation (Baggage arrives promptly after them).

6.1.3.4 V550 - disturbance 5h prior to departure and Vd50 - disturbance ad hoc

There is an incident that leads to an interruption of the journey. In 2050 there is no difference for the traveller between disruptions information from 5h prior and during the journey. In case of disruption, information about it will be available immediately, and if it is necessary, the travellers will be provided with the required actions on their side. The travellers will have a possibility to modify their journey even in a day of journey and select other modes according to his preferences/needs. Disturbances in 2050 resulting from internal reasons like failure or accidents originating outside the system will be very rare. The time for recovery will be extremely short due to using immediate activation of resources of other modes of transport.

VFR traveller groups are provided with all data concerning their multimodal journey at least every hour during the journey. They will have the possibility to modify their journey even on a day of journey (select other modes according to their preferences). Travellers purchase a group ticket for the entire journey with access rights to particular change nodes. The offer will be designed on the base of smart pricing favouring preferred/prioritized modes of transport (with regards to applied policies like carbon footprint or 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 the total system approach applied (System of Systems management). Completed digitalization will allow travellers to make transport mode more fitted to their individual preferences/needs. Luggage is delivered door-to-door.

- Luggage is picked up on short notice before the VFR traveller group starts at home.
- VFR traveller group starts at home: They are using NMS to go to the high-speed train station.
- Traveller is using the high-speed train (digital group ticket for the complete journey purchased shortly before).
- Arrival at the regional airport (passengers were checked in automatically).
- Traveller is using micromobility means of transport at the regional airport. Passenger is in nearly no time at the gate.
- Flight with zero-emission large aircraft.
- Arrival at a hub airport. There are (electric) micromobility means of transport to take the traveller group through the customs to the high-speed rail transport station.

- High-speed rail transport (digital group ticket already purchased at the beginning of the journey). Shortly before arriving at the High-speed rail station, the VFR traveller group got disturbance information about their ferry boat booking (e.g., failure of ferry boat electric). Traveller Group is given an alternative (e.g., autonomous e-taxi ride) to arrive at their accommodation.
- Arrival at the high-speed rail station. There are micromobility means of transport to take the traveller group to the autonomous e-taxi stand.
- Travellers reach the accommodation (Baggage arrives promptly after them).

6.2 Experimental assumptions

For each validation scenario, a set of modelling assumptions has been defined. Where it was possible, the operational characteristics of mobility services were adapted from the corresponding service operators [29]–[33]. All scenario-specific assumptions can be found in section 6.2.2.

6.2.1 Assumptions on passenger profiles

X-TEAM D2D validation experiments intended to simulate also variable behaviour of passengers to release validation results able to represent differences in passengers' needs and, finally, the impact of human variability (according to our passenger centred approach) in terms of “personalized assessment of performances”. In fact, different passengers have different needs and expectations, resulting in multimodal transport systems performing differently depending on the specific passenger type using that service (passenger perspective rather than operator perspective). Given the need to represent passengers’ variability through characteristics that can be measured compatibly with the available metrics adopted for defined KPIs, and considering that a recurring metric is time, the human variable that can be introduced to represent human variability in validation exercises is walking speed. In fact, walking speed varies according to age, physical and sensorial ability, gender, number of group members and many other variables. Table 8 provides walking speed per key passengers’ characteristics [34].

PAX characteristics	Walking speed
Children (< 9 years) with adults (family including children)	Slowest (15th percentile): 1,02 m/s Fastest (85th percentile): 1,41 m/s
Adults < 65	Slowest (15th percentile): 1,22 m/s Fastest (85th percentile): 1,67 m/s
Adults ≥ 65	Slowest (15th percentile): 0,92 m/s Fastest (85th percentile): 1,44 m/s
Impaired people (including wheelchair users, visually impaired persons, and persons on crutches)	Slowest (15th percentile): 0,86 m/s Fastest (85th percentile): 1,49 m/s

Table 8. Walking speed per passenger category

In a further step, the passengers’ population sample has been built according to demographic and other changes foreseen in three scenarios (i.e., more impaired people travelling in 2035, more aged business travellers in 2030 [18]). This population sample is shown in Table 9.

Category	2025	2035	2050
% of BT passengers > 65	5,8% [35]	7% (Assuming that until 2035 retirement ages increase but with significantly different extent among EU countries)	9% [36]
% of VFR passengers with impairments [37]	6%	8%	10%
% of VFR passengers > 65 (assuming that older and retired people travel more)	19%	25%	32%
% of VFR passengers including children	10% [38] (NB this is the percentage of 0-9 year EU population)	9% (assuming that negative demographic trends will stop after EU governments change their policies, that are yet to come)	12% (assuming that new positive demographic policies and reinforced migration/integration flows will occur in the timeframe 2030-2040, also due to increasing migration pressures)

Table 9. Passengers' composition

The walking speed differences between different PAX characteristics were translated into walking speed distributions as listed in Table 10 and Table 11.

Business PAX category	2025	2035	2050	Walking speed, m/s
Older than 65	5.8%	9.0%	25.0%	Normal(1.18, 0.2508622)
Younger than 65	94.2%	91.0%	75.0%	Normal(1.445, 0.2170928)

Table 10. Profile B passengers' composition and walking speed assumptions

VFR PAX category	2025	2035	2050	Walking speed, m/s
Without children & younger than 65	65%	58%	46%	Normal(1.445, 0.217)
Older than 65	19%	25%	32%	Normal(1.18, 0.251)
With children	10%	9%	12%	Normal(1.215, 0.188)
With impairments	6%	8%	10%	Normal(1.175, 0.304)

Table 11. Profile V passengers' composition and walking speed assumptions

Furthermore, for performing simulation experiments, it was assumed that PAX leave their homes at certain times. These assumptions are listed in Table 12.

Co-funded by the European Union

Feature	APT of origin	Profile B	Profile V	Comments
Total number, persons	regional	1000	1000	Maximum number of groups generated
Interarrival time, min	regional	uniform (0,30)	uniform (0,30)	time between groups of PAX
Arrival rate, PAX groups	regional	uniform (0,10)	uniform (0,10)	how many PAX groups arrive at a time
Group size, persons	regional	1	Uniform (1,4)	number of people in the group
Speed, km/h	regional	According to Table 10	According to Table 11	walking speed
Start time	regional	05:00	07:00	when first PAX start their journey
End time	regional	23:00	20:00	when last PAX start their journey

Table 12. Experiment assumptions for generating passenger profiles in 2025, 2035, and 2050

6.2.2 Assumptions on transport modes

The following assumptions have been considered in the CVSF:

General assumptions

- All passengers have pre-purchased travel tickets; therefore, no purchasing time was considered during the journey.
- Travelling time in the first transport modality also includes walking time to the first transport station from the passenger's origin location.
- All transport modes in 2035 and 2050 are carbon-neutral (electric transport).

Air transport

- Flight Hannover-Amsterdam always departs at the scheduled time.
- Flight Hannover-Amsterdam’s schedule corresponds to the schedule in 2021 [39].
- Embarkment on the aircraft always ends 20 minutes prior to the departure time.
- If passengers arrived at the gate after the end of the embarkment, they had to stay at the airport to take the next flight on the schedule.
- Flight time considers the time between the aircraft take-off at the regional airport and landing of the aircraft at the hub airport.
- eVTOL and ATM operation does not consider possible airspace limitations and regulations.
- eVTOL embarkment and control procedures /de-boarding take three to ten minutes per person.
- Differences in piloted and unmanned eVTOL operations are not considered.

Road transport

- Owing to the fact that at the moment of performing the ConOps validation exercise, there was no information regarding the future design of road networks in Germany and the Netherlands, and it is extremely difficult to forecast such development, the road infrastructure and its operational conditions were assumed to remain unchanged through all time horizons and correspond to the existing infrastructure state in 2020.
- Bus stops are located in direct proximity to PAX origins.
- Boarding/de-boarding an e-scooter takes five seconds per person.

Railway transport

- The railway infrastructure and its stations' location remain unchanged through all time horizons and correspond to the existing infrastructure state in 2020.
- The train schedule remains unchanged and corresponds to the schedule in 2020 published by Dutch Railways [32] and German Railways [33].

Water transport

- Water transport operates under the speed regulations and uses navigable inland waters existing in 2020 in the North Holland province of the Netherlands [40].
- Ferry boarding/de-boarding takes five seconds per person.

Other mode-specific and detailed overviews of assumptions for each time horizon can be found in Table 13, Table 14 and Table 15.

Mode	APT type	Capacity of one unit	Average speed, km/h	Arrival mode	Interarrival time, min	Activity radius/ ride duration	Availability
bus Home - train Brunswick station	regional	143	15	interarrival time	15	Uniform (3,38) min	5:00 – 2:47
train Brunswick-Hannover	regional	391	81.4 or 104.6	schedule	~29min	-	2:36 - 00:20
train Hannover - Hannover APT	regional	391	51.3 V525: Uniform (36, 44)	interarrival time	30	-	04:35 - 01:33
taxi	regional	1 BT/ VFR group	Uniform (80,90)	on demand	Uniform (5,15)	Uniform (53, 76) min	-
car sharing	regional	1	Uniform (65,84)	on demand	Uniform (2,10)	Uniform (50,65) min	-
flight	-	75	-	schedule	06:00 11:25 18:15	Uniform (45,65) min	-
train Amsterdam APT - Amsterdam	hub	391	70±10	interarrival time	6	-	05:00-01:00
Train Amsterdam - Haarlem	hub	391	100±10	interarrival time	9	-	05:00-01:00
bus	hub	50	33.8	interarrival time	6	Uniform (5, 40) min	-
taxi	hub	1 BT/ VFR group	Uniform (50, 57)	on demand	-	Uniform (19, 23) km	-
rental car	hub	1 BT/ VFR group	Uniform (50, 57)	on demand	Uniform (10,15)	Uniform (19, 23) km	-

Table 13. Experiment assumptions for transport modes in 2025

Mode	APT type	Capacity of one unit	Average speed, km/h	Arrival mode	Interarrival time, min	Activity radius/ride duration, min	Availability
e-scooter	regional	1	50	on demand	0	Uniform (5,15)	-
eVTOL	regional	4	200	on demand	0	Uniform (18,20)	-
bus Home - Brunswick station	regional	143	15	interarrival time	15	Uniform (3,38)	5:00 – 2:47
train Brunswick-Hannover	regional	391	81.4 or 104.6	schedule	~29min	-	2:36 - 00:20
train Han - Han APT	regional	391	51.3 V525: Uniform (36, 44)	interarrival time	30	-	04:35 - 01:33
e-car sharing	regional	1	uniform (30,50)	on demand	-	Uniform (1, 5) km	-
e-car sharing VFR	regional	1	uniform (65,84)	on demand	Uniform (2,10)	Uniform (69, 71) km	-
e-taxi	regional	1 BT/ VFR group	uniform (80,90)	on demand	Uniform (5,15)	uniform (47,53)	-
flight	-	75	-	schedule	06:00 11:25 18:15	uniform (45,65)	-
e-car sharing	hub	1	uniform (50,57)	on demand	Uniform (10,15)	Uniform (19, 23) km	-
train AAS - AMS	hub	391	70+-10	interarrival time	6	-	05:00-01:00
Train AMS - Haarlem	hub	391	100+-10	interarrival time	9	-	05:00-01:00
bus	hub	50	33.8	interarrival time	6	uniform (5, 40)	-

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Table 14. Experiment assumptions for transport modes in 2035

Mode	APT type	Capacity of one unit	Average speed, km/h	Arrival mode	Interarrival time, min	Activity radius/ride duration, min	Availability
e-scooter	regional	1	50	on demand	0	Uniform (5,15)	-
eVTOL	regional	4	200	on demand	0	Uniform (10,15)	-
highspeed train Brunsw-Han	regional	391	200	schedule	~29min	-	2:36 - 00:20
highspeed train Han - Han APT	regional	391	200	interarrival time	30	-	04:35 - 01:33
flight	-	75	-	schedule	06:00 11:25 18:15	Uniform (45,65)	-
ferry	hub	50	60	on schedule	10	19.2 km	05:00 - 01:00
e-scooter	hub	1	50	on demand	-	-	-
e-taxi	hub	1 person/ family	uniform (50, 57)	on demand	-	Uniform (19, 23) km	-

Table 15. Experiment assumptions for transport modes in 2050

7 ConOps validation results

After the ConOps validation approach has been verified by the Advisory Board experts, and validation experiments for all time horizons and passenger profiles have been executed in the simulation framework, the X-TEAM D2D consortium experts have analysed their results during the execution of tasks 5.2 “Evaluation of Extended ATM transport system performances” and 5.3 “Conclusions and recommendations”. These results are discussed in this section.

7.1 Plausibility verification results

The experts provided feedback on diverse aspects. After the interaction, some actions were considered for future follow-up projects and others were considered for improvement of the current document and reporting of the activities of the project.

As the ConOps validation approach was considered plausible by the experts, the results obtained in the ConOps validation exercise can be considered as likely values to be obtained once the different mobility modes/vehicles are in place. Due to the nature of the project and time horizons considered, the quantities obtained are values that cannot be verified with traditional quantitative techniques such as statistical tests or hypothesis tests, and the values are preliminary that can be further analysed with a follow-up project that considers elements as the following ones suggested by the advisory board:

- Considering the probability of failure
- Considering the meta-modelling using complex networks to identify potential issues
- Put the focus on the interfaces between the transport modes
- Considering Additional on-demand vehicles
- Analysis of the division of social categories of passengers
- Consideration of luggage flow
- Considering Behavioural aspects
- Analysis of energy requirements
- Evaluate the feasibility of logistics concepts such as synchromodallity
- Consider specific forecasts for the region under study
- More details of the future vehicles will be considered, e.g., vertiports dimensions or location
- Risk analysis
- Extra scenarios for the experimental design

After the ConOps validation approach passed the plausibility verification, it was assumed that ConOps was a valid alternative for the horizons considered. The results should be taken with the limitations/considerations of the assumptions defined in the project.

7.2 Simulation framework verification and validation results

Verifying the developed simulation framework is essential to obtain reliable and representative data regarding the transportation system's performance. Model verification ensures that the computerized model and its implementation correctly represent the target problem or system under study [21].

The CVSF was verified using the combination of the following techniques:

- Graphical Verification. The model's operational behaviour was followed using the graphic elements at hand within the platform. The correctness of the models' behaviour was confirmed visually by following the paths of the different elements.
- Trace. The behaviour of passengers and transport vehicles in CVSF was followed quantitatively through the model to confirm whether the models' logic is correct. The general-purpose discrete event simulation software used to develop CVSF provided trace capability.
  Comparison to assumptions/input data. The models' output for simulated passenger journeys was compared to the data from assumptions. As in the example shown in
- Figure 21, the expected performance is compared to the one developed by the model considering the input assumptions.

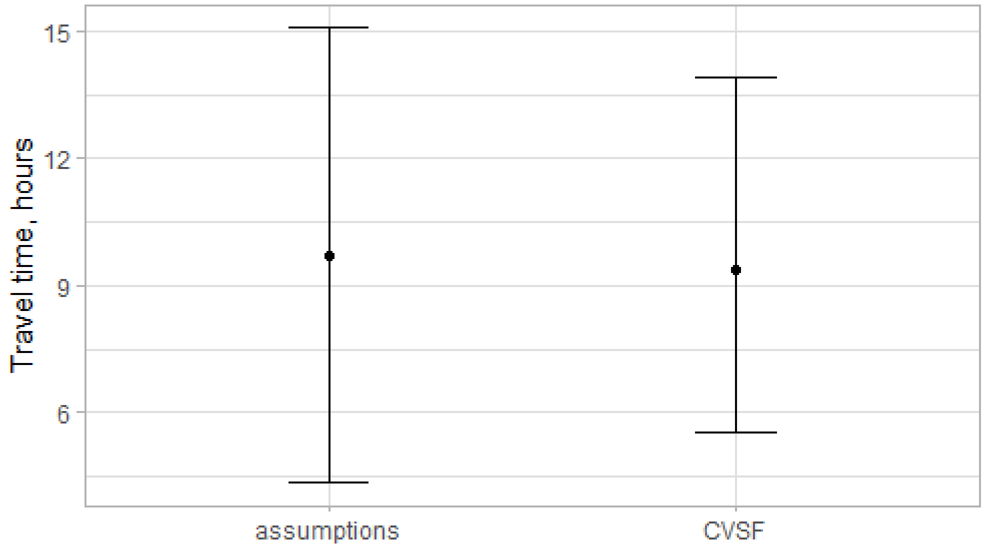


Figure 21. Comparison of assumed travel times and results obtained in CVSF for VFR passengers in V025.

The next step is a validation of the models composing CVSF. In X-TEAM D2D, the target system is analysed under three states, representing transportation systems in 2025, 2035 and 2050. As these states mainly contain technologies that have not been deployed for public use when writing this validation report, the CVSF was verified against the assumptions considered for 2025, 2035, and 2050 and described in section 6.2.2.

As shown in Figure 21, the developed CVSF performs within the assumptions. Mean values only differ by 4-10%, which was accepted by consortium experts. Note: as CVSF have many stochastic elements, it is impossible to calculate how these elements behave together; therefore, the difference with the calculated assumed travel times is unavoidable. Considering the aforementioned, CVSF has been accepted as verified and valid for performing ConOps validation experiments.

7.3 ConOps validation exercise' results

After repeating the simulation run 50 times for each scenario, the results provided the multimodal system behaviour for the horizons of 2025, 2035 and 2050. The following sections describe the results obtained in terms of two key performance areas.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

7.3.1 D2D journey efficiency

The first KPA of the focus is D2D journey efficiency, which covers Total distance travelled, Total travel time, and Average travel speed per passenger. Figure 22, Figure 23 and Figure 24 show the statistics obtained for these KPIs.

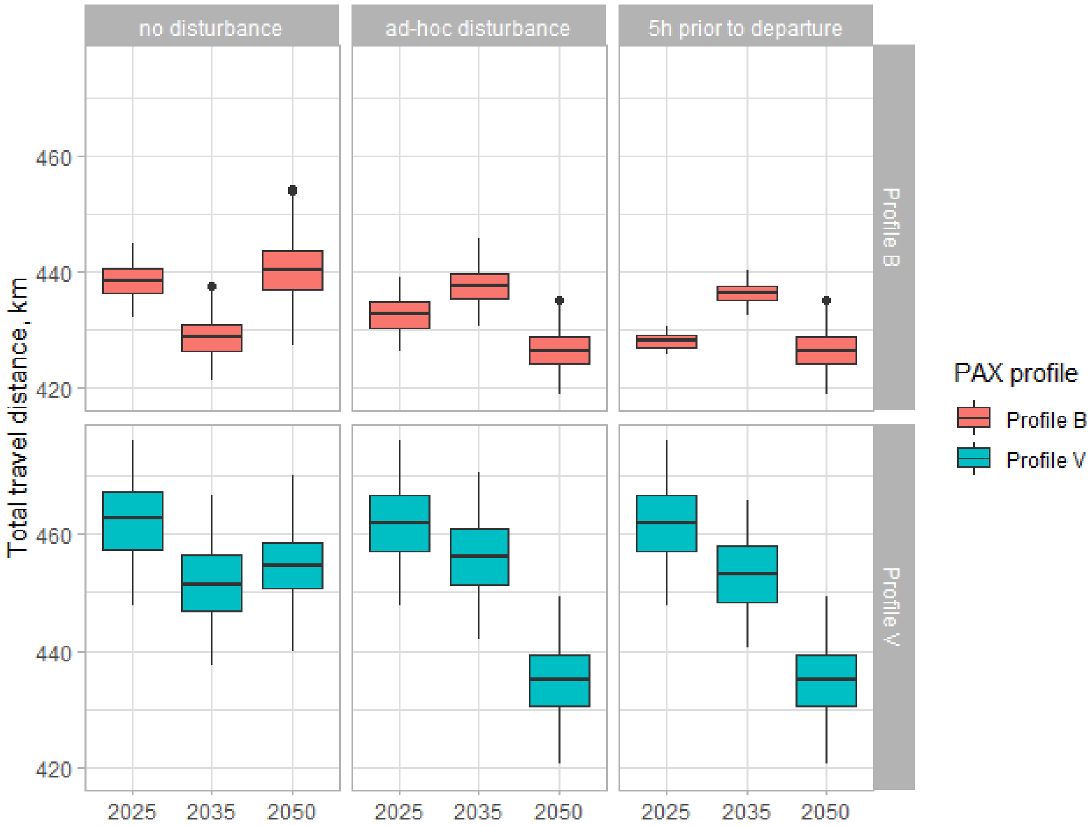


Figure 22. Total travel distance statistics (including flight segment)

When comparing travel distance (Figure 22) across time horizons for business passengers (Profile B), it can be noticed that this type of passengers can cover approximately 1% longer distance in 2050 compared to 2025. However, in the case of disruptions in 2050, the multimodal travel distance can be reduced by 3% compared to the scenario without disturbances. For VFR travellers, these differences are two times larger, and the multimodal system in 2050 provides these travellers with a 5% shorter travel distance regardless of the disruptions presence.

Figure 23. Total travel time (including flight segment)

In terms of total travel time, as shown in Figure 23, VFR travellers will win the most from the multimodal network design in 2050. In this time horizon, the journey efficiency seems to be unaffected by disruptions. The average total time is 20% less than in 2025. For business travellers, the average travel time improvement between 2025 and 2050 is 22%.

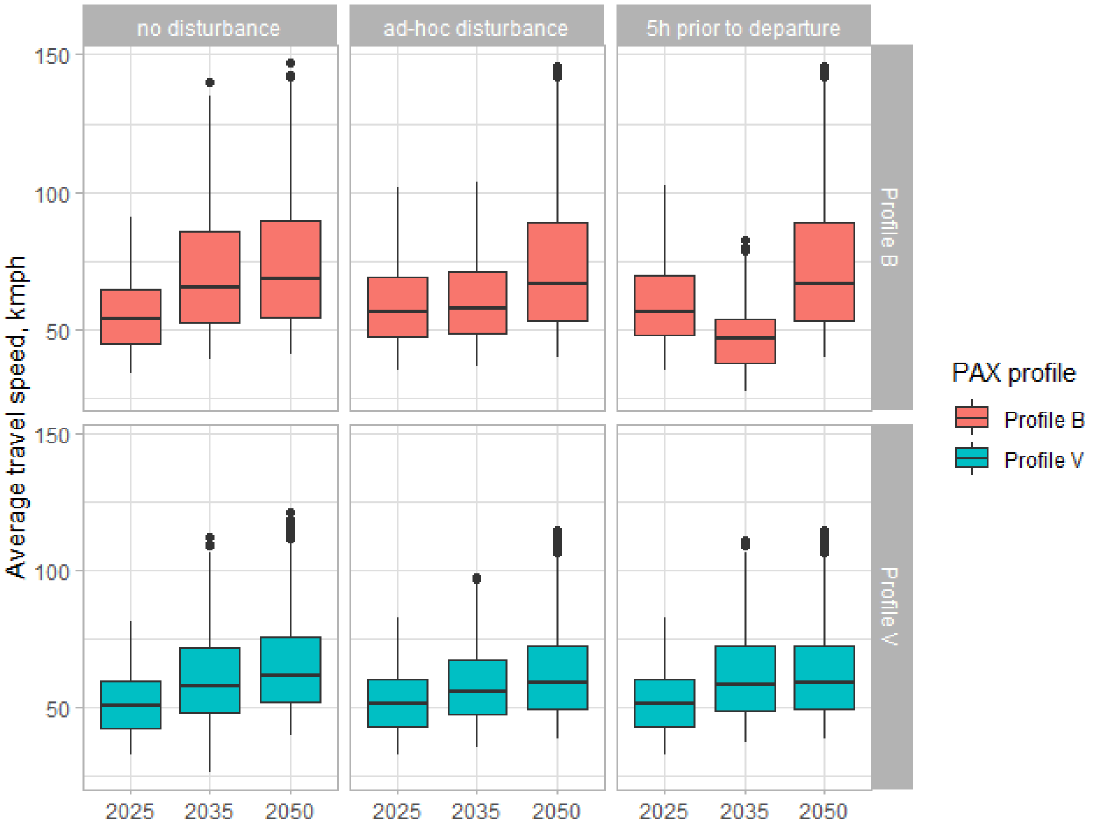


Figure 24. Average travel speed statistics (including flight segment)

When talking about the average speed of travel, it can be noticed that by 2050 the travel speed will increase by 21% on average for both passenger profiles. Notable that in 2035 disruptions slow the travelling of business passengers; however, in 2050, disruptions no longer impact their average travelling speed.

Discussion

Regarding this KPA, some relevant aspects need to be considered. The first one is the aspect related to the *travel time and resilience* of the system. Based on Figure 23, there is a clear tendency for a reduction in travel time with the introduction of new and more transport modes. The travel times are reduced for the V and B passengers in the cases with no disturbance and with disturbance. This behaviour reveals that as the time horizons develop further into the future, the infrastructure becomes more efficient, and it impacts the reduction of travel time for the passengers directly. Furthermore, in the cases of disturbance, the system becomes quite resilient as the total times in 2050 are not importantly affected by the disturbance for the business and normal passengers. This resilient structure is caused by the novel alternatives that are offered to the different passengers with even higher speeds (see Figure 24). With regards to Figure 22, presenting the impact on total travel distance, in general, when there is a disturbance, the distance could be increased in some cases (see the year 2035), but the passengers are forced to use a faster and more expensive mode to get to their destination. In this project, the experiments did not consider economic factors; however, these results reveal that it could be an interesting indicator to consider so that the balance between efficiency and cost is more transparent.

7.3.2 D2D journey quality

One of the most important aspects of travelling for passengers is waiting time at interconnections, as discussed in section 5.2. Figure 25 shows waiting time statistics obtained in the ConOps validation experiments.

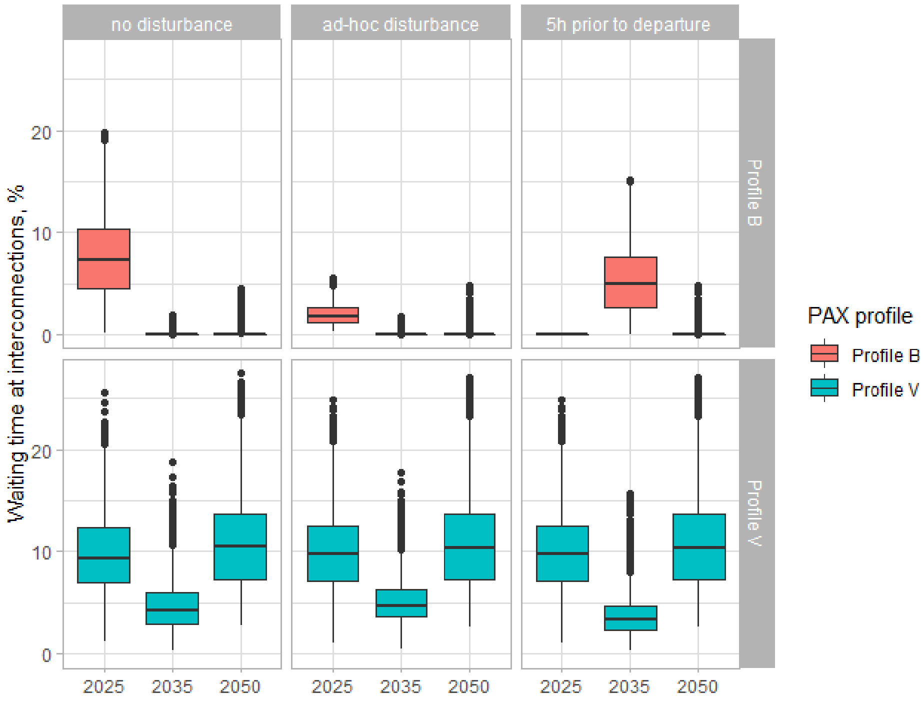


Figure 25. Waiting time at interconnections compared to total travel time (excluding flight related waiting at the airports)

It is important to note that for business travellers (Profile B), higher waiting time corresponds to the scenarios with public transport operating on schedule (trains & buses). When business travellers use on-demand operating transport like UAM or NMS (in 2035 and 2050), the waiting time is significantly reduced or is close to zero. VFR passengers are more dependent on mass forms of public transport; therefore, significant waiting time values can be seen in Figure 25. The lowest waiting times for Profile V correspond to the scenarios for 2035, where passengers use on-demand transport services.

Discussion

This KPA reveals that the quality of service for Business and VFR passengers is quite different. Business passengers have the option of demanding a fast and efficient solution when there is a disruption (see 2035 and 2050 values for B PAX). On the other hand, the VFR passengers do not have that opportunity; it is noticeable that when there is a disruption in 2035, they wait more at interconnections as they connect to a transport operating on a scheduled basis. For VFR passengers, the average waiting time in 2025 almost reaches one hour, which is a significant loss of time in terms of comfort, especially for passengers with impediments and travelling with children. It is worth noting that the framework was not considering yet an algorithmic governing layer that might be in the future, i.e. there is no decision support tool modelled that plans in an intelligent way the travel of any passenger (VFR or B passengers). This capability should be further investigated in a follow-up project.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

8 Guidelines for design and performance assessment of passenger-centric integrated intermodal transport, including surface and air travel service

8.1 Performance objectives

Performance reviews can provide an effective means of measurement capabilities difficult to measure with a complex system characterized by the integration of several systems. Performance evaluations consist of a task and a set of scoring guidelines. Performance tasks must be chosen carefully. This chapter examines the design of appropriate performance activities, keeping in mind that a good evaluation is in line with the standards which the measures required. A well-defined score rubric is essential for reliable measurement. A performance assessment consists of is to identify the phenomenon or an engineering problem that fits the performance expectation that is trying to assess and a set of scoring criteria or a scoring rubric. In this way, assessment becomes phenomenon-based and multidimensional as it assesses both services and technologies.

How to design a performance assessment as move away from traditional assessment strategy. The purpose of assessment begins to shift. Instead of only measuring system performance, it also strives to create an opportunity to learn throughout the process; the feedback is far richer than traditional assessment. This allows for gathering more information about the system.

In the next section, is described a sequence of steps used to design a performance assessment of passenger-centric integrated intermodal transport, including surface and air travel services. While is defined a clear and meaningful sequence for this process, is needed to emphasize that it is iterative in nature and often requires returning to earlier steps.

8.1.1 The performance expectation

The first step of designing a performance assessment is to unpack the performance expectation. This Unpacking means digging into ConOps to interpret what the performance expectations really mean; this ensures that performance assessment satisfies what you want it to assess. Bearing in mind that the ambition of the X-TEAM D2D is the one providing, for the first time, an all-in-one approach (ConOps and Validation tool).

This innovative methodology, apart from performing the specification and analysis of future operations, provides a validation tool that will increase transparency, replicability, and accuracy in the outcomes of the project.

8.1.2 ConOps Design

The process of brainstorming a suitable ConOps often starts by looking at the elements of the system and connecting these concepts to some way. The key to this step is to keep an open mind and remain willing to change the ConOps if the first idea does not quite fit.

Moreover, the ConOps of a system describes the characteristics of a certain paradigm from a user's perspective. It gives qualitative and quantitative details of how the system should be used and how it should behave. In particular, the ConOps is expected to include the identification and description of:

- the **elements** of the system, i.e., all the constituent parts of the examined system relating to the available technologies, the infrastructures that make it possible to manage these elements, the IT components that allow the necessary exchange of data and information;
- the **space** to be assigned to the elements of the system, i.e., the volume within which they will be confined and the set of procedures designed to support safe, efficient and secure access to this space;
- the **actions** within the system, which include all possible operations concerning the elements involved as well as the various services offered and the access conditions required, also considering any **space types** into which the elements of the system have been divided;
- the procedures to overcome **emergencies** in order to mitigate risks or resolve them successfully, ensuring the safety of the operations also in non-nominal situations.

Therefore, the second necessary step will be to define and differentiate the elements of the system. In particular, the following distinctions should be made:

- Actors (actions)
- Means (essential constituent parts)
- Infrastructures (infrastructural elements)
- Interfaces (IT components)
- Services

Thus, by identifying all the components of the examined system, evaluating the possible actions that can be carried out in the allowed spaces and analyzing the different relationships existing between the various elements considered, it is possible to design the desired ConOps.

In particular, for passenger-centric integrated intermodal transport, the following list is shown, which includes the transport technologies (aircraft, vehicles, etc.) that will support the Multimodal Mobility. 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”.

<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 multimodal transport, the architecture of the intermodal system is "ATM-centred". Therefore, the air transport modes and, in particular, the Urban Air Mobility play a very central role. For this reason, it is necessary to take into account their accurate technological roadmap, also considering the need to detail their evolution along the three time horizons considered, i.e. 2025, 2035, and 2050.

8.1.3 ConOps Validation

This design step is to develop ConOps and validation instructions that focus on the system and elicit evidence of all dimensions. Analysing and Interpreting data, gathered data relevant.

The research study that inspired this choice in ConOps provides graphs showing the change in three time horizons. While the output for this task came in a traditional format and was easily accessible from one source, simulation data come in many different forms, and this data collection process needed much more effort. Since the data are not the result of an observed phenomenon, generally, data come out in the form of observations, measurements, and calculations resulting from carrying out an investigation or doing a simulation.

In this specific case, data are the output of a very complex, multidisciplinary forecast analysis. Because data are not available in a form that is accessible, was used scientific concepts to manufacture data sets.

When starting to write a validation plan, always keep in mind that this type of evaluation requires a commitment to a new and very complex thought process. In order to help understand the ConOps and engage with difficult multidimensional questions, it is also needed to build in scaffolding questions that provide all access to the assessment.

This tool helps to organize and make sense of data independently and accomplish this performance assessment; in addition, it also provides an edge of concepts.

The effort made was to obtain a scientific explanation based on valid and reliable elements obtained from certified sources based on the principle that the theories and laws that describe the systems are universal over time, have been valid in the past, are still valid today and will be valid in the future, to understand appropriate scientific concepts in order to support performance assessment.

8.2 Performance assessment

Upon drafting a performance validation plan, the last step is to create a scoring guide that includes rubrics that clearly assess the three dimensions of the performance assessment.
For this purpose, we worked by defining in the first place the KPA and then the KPI, which are useful for performance analysis.

In defining these criteria, the first element was to clarify the idea of what they are looking for. This approach ensures that created a multidimensional rubric, meaning it assesses the integration of multiple systems rather than assessing only content. We will summarize the key components here. Understanding the steps of the design process is essential. Like any new process, designing performance analysis of this kind of ConOps was challenging.

Everything just described is the output of various studies and documents made through the various WPs of the project. Starting from the definition of future reference scenarios and barriers analysis with which, it is possible to understand the definition and description of crucial specifications of the systemic environment in which future integrated metropolitan and regional transport would operate.

This is a foundation for the definition of the Concept of operation defining the role of ATM and air transport in three considered time perspectives: 2025, 2035 and 2050. Both in terms of physical and informational dimensions, through the analysis of future scenarios: defining the reference scenarios and dominating trends in urban and suburban mobility, passing to the analysis of technologies for urban/suburban mobility, through identification and evaluation of new technologies related to transport modes representing potential to significantly impact the intermodal mobility in three time horizons; an important step was Identification of specific use cases for the intermodal transport system including ATM and air transport with reference to the three considered timelines.
Finally, it was necessary to identify the Barriers against and transport integration of air and surface modes of transport.

The core activities were done starting from an initial definition of the Concept of Operations (Concept Outline) for ATM integration in the intermodal transport system and then subsequently refined, arriving at the definition of a Concept of Operations (Concept Description) supporting the seamless integration of ATM into an overall intermodal network from the perspective of the transport systems and infrastructures. By defining the technological enablers at each time horizon, and consequently defining three different architectures, as well as evaluating the integration aspects from the service point of view. Furthermore, analysing the system from the point of view of passengers' needs.
Finally, the last phase of the project address the validation of a Concept of Operations (ConOps) from the passengers' perspective and overall multimodal system performance based on the corresponding KPAs and KPIs.

The approach for generating the rubric scoring on which this project was based was through the definition of the KPAs and KPIs was applied to these indicators; the approach that provides for the definition of the criteria to which a measurable performance rating is applied.
Finally, to complete the description of the single criterion, as shown in Figure 26, there is an extract of Table 6 in which the overview of the KPIs is schematised.

KPA	Nr	KPI	Measurement	Comments	Estimated in this study?
CRITERIA			PERFORMANCE RATING	PERFORMANCE DESCRIPTION	
D2D journey efficiency	1	Total distance travelled	Door-to-door for each PAX	measured for each PAX	Yes
	2	Total travel time	Door-to-door for each PAX	measured for each PAX	Yes
	3	Average travel speed	KPI 1/ KPI 2	measured for each PAX	Yes
D2D journey quality	4	Waiting time at interconnections	(Egress – Access time)/KPI 2	measured for each PAX	Yes
	5	Frequency (probability) of delays from breakdowns/maintenance etc	Total time of delay/total operating time (on weekly/monthly base?)	measured per operating line by the mode operator	No
	6	Accessibility of wayside infrastructures	Number of architectural barriers encountered/number of obstacles	Measured per mode	No
	7	Luggage security	Lost and stolen probability	measured for each PAX	No
	8	Ticketing user-friendliness	Mean time spent for ticketing	measured for each PAX	No

Figure 26. KPI score rubric offprint

The way to interpret these indicators is based on the analysis of these criteria. To understand the ConOps validation experiments we have to look at the simulation framework developed in WP5 as described in section 4.4.

After understanding the criteria, the ConOps validation design, its assumptions, and bearing in mind the preliminarily defined scenarios, are available the tools to understand the results of the validation of the Concept of Operations for ATM integration in the Intermodal Transport System.

In particular, the following guidelines can be provided:

- to consider defining scenarios such as those described in the flowcharts presented in Appendix A and, most importantly, their subdivision into legs which makes it possible to split a complex problem into more manageable parts.
- to evaluate the probability distributions with which the various modes/means of transport occur in the previously defined scenarios (for example, their frequency and waiting times).
- To simulate the scenarios thus appropriately structured, obtaining the desired results (through the performance of the previously defined KPIs) and highlighting them with easily interpretable graphs.

9 Conclusions and recommendations

This document presents the methodological approach for validating ConOps of the X-Team D2D project and its results. According to the Advisory Board, all assumptions used in developing the conceptual framework are reasonable up to the current state of the art of the technology that is expected in 2025, 2035, and 2050. For answering the main question raised at the beginning of this project related to resilience, travel times, quality of service and, for the first time, expectations towards the 4hr Door-to-door travelling, the following conclusions can be made. These conclusions are based on the scientific methodology that used a simulation framework that enabled to put into practice all concepts, technologies and implementations expected to be in 2025, 2035 and 2050.

Regarding the *Resilience* of the system, we can conclude from the experimental results that the system will increase its resilience to disruptions in the coming years with the new technological developments. Owing to the options and alternatives for travel that passengers will have in the future, the travel from door to door will be very reliable.

Regarding *travel times*, the system seems to evolve toward reducing time travel. It is expected that the travel time will be reduced with the inclusion of faster and more efficient modes of transport. Based on the experimental results, we expect that in some cases, the developed ConOps result in a reduction of travel time of around 40% for business and 20% for regular passengers. Regarding the FlightPath 2050 goal of 4hr-door-to-door travelling, it was proved that this goal is achieved only for a few cases, as in the average the travel time norms 5hr for business travellers and 6 hrs for regular passengers in 2050. This might partially be because under the current assumptions, we did not consider a reduction in time spent at the airports. However, it is likely that all the processes required to undergo at the airport will be faster in the future. This is also proposed as a future line of research.

Regarding the service levels measured in time waiting at interconnections, we identified that considering the project's assumptions, the VFR passengers are more exposed to delays in future travel. This may be due to the scheduled mass transport of the future (high-speed trains mainly); however, we did not consider in this project that in the future, we expect more algorithmic governance (intelligent apps) that will support passengers' planning their trips in an efficient way. This is also proposed as a future research line.

To summarise, we could identify several areas that require further research, and we propose as part of follow-up projects or research:

- According to the assumptions implemented in the framework, the time within the airport does not change in the future. The reason for this assumption is that the X-Team D2D scientific group did not focus on the evolution of technology within the airport terminal buildings; therefore, we could not foresee a plausible reduction of travel time inside the airports. This line of research could be incorporated into a follow-up project.
- We did not consider the algorithmic governance of travel in the future, i.e., intelligent technology will be in place for supporting passenger travel with the consequence of the reduction in time. This should be investigated to evaluate its impact on the different KPIs for the different stakeholders in place.
- We recommend revising the initial assumptions and making a future study on the modal connections to identify if it is possible to reduce the travel times even more.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Furthermore, after the plausibility verification exercise was performed with the Advisory board, we identified some elements that need to be considered in future and follow-up projects:

- The cost of travel should be considered in the simulation study to identify the tipping points where it discourages the use of a particular transport mode
- Emissions and associated environmental risks should be considered as another dimension in the study
- Future availability of other technologies and transport modes, among others, should be included in the study as well (see section 7.1).

As the technological state of transportation systems is constantly evolving, the scientific participants of X-Team D2D strongly suggest using the presented simulation-based approach to support the planning of implementation of future technologies so that it is possible to foresee potential obstacles and requirements for integrating novel technologies in the current systems in place.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

10 References

In this deliverable, the following sources have been used as correspondingly cited throughout the document.

[1] "H2020-SESAR-2019-2 (ER4), SESAR JU, Edition 4, 25 April 2019." .

[2] X-TEAM D2D, "Deliverable D3.1 'Concept of Operations for ATM integration in intermodal trasport system [Concept Outline],'" 2021.

[3] X-TEAM D2D, "Deliverable D3.2 'Concept of Operations for ATM integration in intermodal trasport system [Concept Description],'" 2022.

[4] X-TEAM D2D, "Deliverable D4.1 'Concept of Operations for ATM service to passengers in intermodal trasport system [Concept Outline],'" 2021.

[5] X-TEAM D2D, "Deliverable D4.2 'Concept of Operations for ATM service to passengers in intermodal trasport system [Concept Outline],'" 2022.

[6] ICAO, "Manual on global performance of the air navigation system (Doc 9883), p I-1-1.," 2009. https://www.icao.int/SAM/Documents/2020-RLA06901-ANPVOLIII/1_2_Doc. 9883 GPM.pdf (accessed Feb. 24, 2022).

[7] A. M. de Souza, C. A. R. L. Brennand, R. S. Yokoyama, E. A. Donato, E. R. M. Madeira, and L. A. Villas, "Traffic management systems: A classification, review, challenges, and future perspectives:," *http://dx.doi.org/10.1177/1550147716683612*, vol. 13, no. 4, p. 2017, Apr. 2017, doi: 10.1177/1550147716683612.

[8] SESAR Joint Undertaking, "European ATM Master Plan - Roadmap for the safe integration of drones into all classes of airspace." 2018, Accessed: Feb. 24, 2022. [Online]. Available: https://www.sesarju.eu/node/2993.

[9] EUROCONTROL, European Commission, European Aviation Safety Agency, and SESAR Joint Undertaking, "U Space Services - Implementation Monitoring Report," 2018. https://www.eurocontrol.int/sites/default/files/publication/files/u-space-services-implementation-monitoring-report-ed-1.2.pdf (accessed Feb. 24, 2022).

[10] Z. Liu and C. Wang, "Design of traffic emergency response system based on internet of things and data mining in emergencies," *IEEE Access*, vol. 7, pp. 113950–113962, 2019, doi: 10.1109/ACCESS.2019.2934979.

[11] D. Diran, A. Fleur VAN VEENSTRA, T. Timan, P. Testa, and M. Kirova, "Artificial Intelligence in smart cities and urban mobility," 2021.

[12] EUROCONTROL, "THE MANUAL: Airport CDM Implementation ." 2017.

[13] S. Hoogendoorn *et al.*, "The Future of Traffic Management - State of the Art, Current Trends and Perspectives for the Future," 2011. doi: 10.13140/RG.2.1.1007.0568.

[14] Australian Government and T. Department of Infrastructure, "The Whole Journey: A guide for thinking beyond compliance to create accessible public transport journeys."

https://www.infrastructure.gov.au/infrastructure-transport-vehicles/transport-accessibility/whole-journey-guide/guide (accessed Feb. 24, 2022).

[15] Deloitte, "Urban air mobility What will it take to elevate consumer perception?" .

[16] "Concept of Operations for the Next Generation Air Transportation System. Version 3.2." https://apps.dtic.mil/sti/citations/ADA535795 (accessed Feb. 24, 2022).

[17] Deloitte, "Benefit Analysis of Drones in Australia," 2020. Accessed: Feb. 24, 2022. [Online]. Available: www.deloitteaccesseconomics.com.au.

[18] X-TEAM D2D, "Deliverable D2.1 'Future Reference Scenarios and Barriers,'" 2021.

[19] A. Kwasiborska, J. Skorupski, and I. Yatskiv, *Advances in Air Traffic Engineering*. Cham: Springer International Publishing, 2021.

[20] X-TEAM D2D, "Deliverable D5.1.010 'Validation Plan,'" 2021.

[21] R. G. Sargent, "Verification and validation of simulation models," *Journal of Simulation 2012 7:1*, vol. 7, no. 1, pp. 12–24, Dec. 2012, doi: 10.1057/JOS.2012.20.

[22] M. M. Mota, A. Di Bernardi, P. Scala, and G. Ramirez-Diaz, "Simulation-Based Virtual Cycle for Multi-Level Airport Analysis," *Aerospace 2018, Vol. 5, Page 44*, vol. 5, no. 2, p. 44, Apr. 2018, doi: 10.3390/AEROSPACE5020044.

[23] OpenStreetMap Contributors, "OpenStreetMap." https://www.openstreetmap.org/#map=8/52.154/5.295 (accessed Apr. 09, 2022).

[24] Transportation Research Board, *Performance-Based Measures in Transit Fund Allocation*. Washington, D.C.: National Academy Press, 2004.

[25] L. Kraus, H. Proff, K. Doi, and A. M. Fillone, "Sustainable Urban Transportation Criteria and Measurement—A Systematic Literature Review," *Sustainability 2021, Vol. 13, Page 7113*, vol. 13, no. 13, p. 7113, Jun. 2021, doi: 10.3390/SU13137113.

[26] CONDUITS (Coordination Of Network Descriptors for Urban Intelligent Transport Systems), "Deliverable No. 3.5: Key Performance Indicators for traffic management and Intelligent Transport Systems," 2011.

[27] T. A. Litman, "Well Measured Developing Indicators for Sustainable and Livable Transport Planning Well Measured: Developing Indicators for Sustainable And Livable Transport Planning," 2021. Accessed: Feb. 23, 2022. [Online]. Available: www.vtpi.org.

[28] K. G. Troitzsch, "Analysing simulation results statistically: Does significance matter?," *Interdisciplinary Applications of Agent-Based Social Simulation and Modeling*, pp. 88–105, Apr. 2014, doi: 10.4018/978-1-4666-5954-4.CH006.

[29] Connexxion, "Up-to-date travel information," 2021. https://www.connexxion.nl/en/travel-information/up-to-date-travel-information (accessed Sep. 10, 2021).

[30] Electric Scooter Guide, "Best Electric Scooters of 2021: According to Science And Exclusive Data," 2021. https://electric-scooter.guide/best-rated/best-electric-scooters/ (accessed Sep. 10, 2021).

[31] EV Database, “Top speed of full electric vehicles cheatsheet,” 2021. https://ev-database.org/cheatsheet/top-speed-electric-car (accessed Sep. 10, 2021).

[32] NV Nederlandse Spoorwegen, “Travel information,” 2021. https://www.ns.nl/en/travel-information (accessed Sep. 10, 2021).

[33] Deutsche Bahn, “Cheap Train Tickets | Timetables for Germany & Europe - Deutsche Bahn,” 2021. https://www.bahn.com/en (accessed Feb. 22, 2022).

[34] T. J. Gates, D. A. Noyce, A. R. Bill, and N. Van Ee, “Recommended Walking Speeds for Timing of Pedestrian Clearance Intervals Based on Characteristics of the Pedestrian Population,” *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1982, no. 1, pp. 38–47, Jan. 2006, doi: 10.1177/0361198106198200106.

[35] OECD, “Labour force participation rate,” 2018, doi: https://doi.org/https://doi.org/10.1787/8a801325-en.

[36] Eurostat, “Demography report - Population and demography,” *2020*. https://ec.europa.eu/eurostat/web/population-demography/demography/publications/demography-report (accessed Feb. 23, 2022).

[37] World Health Organization, “Facts on disability,” Feb. 23, 2022. https://www.euro.who.int/en/health-topics/Life-stages/disability-and-rehabilitation/data-and-statistics/facts-on-disability (accessed Feb. 23, 2022).

[38] EUROSTAT, “Population structure and ageing,” *2021*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Population_structure_and_ageing#Slightly_more_than_three_persons_of_working_age_for_every_person_aged_65_or_over (accessed Feb. 23, 2022).

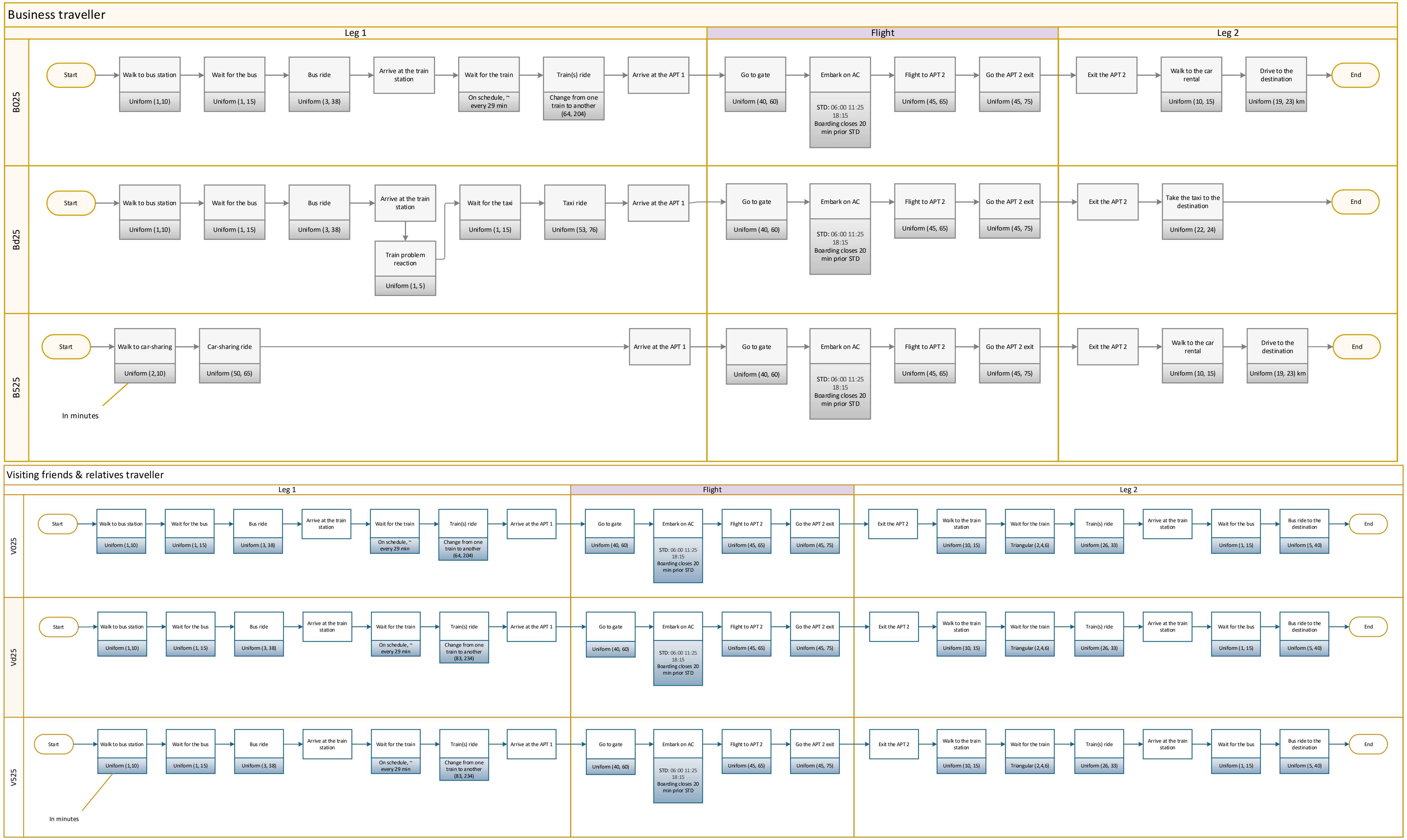
[39] “Departures Hannover Airport.” https://www.hannover-airport.de/rund-ums-fliegen/abflug/?tx_vcairportflugplanxml_pi1%5Baction%5D=showTomorrow&tx_vcairportflugplanxml_pi1%5Bdirection%5D=departure.

[40] Sloepen Netwerk, “Most beautiful boat routes around Amsterdam and Haarlem (in Dutch).” https://cdn.sloepennetwerk.nl/vaarkaarten/vaarkaart-amsteram-en-haarlem.pdf.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

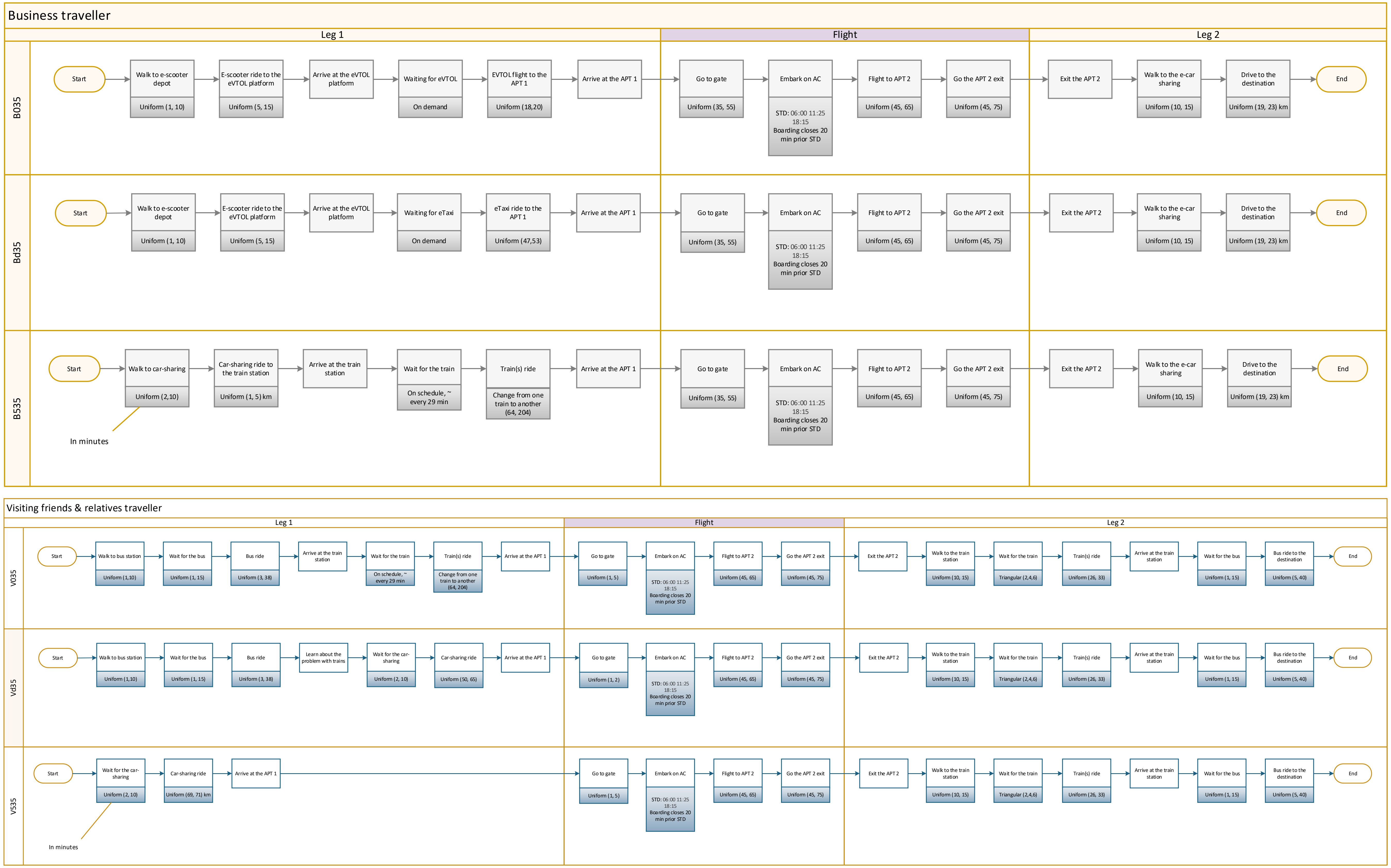
Appendix A Passenger journey in 2025 flowchart (in A3 format)[2]



EUROPEAN PARTNERSHIP
Co-funded by the European Union

[2] Flowcharts were developed in Microsoft® Visio® 2021 MSO (Version 2201 Build 16.0.14827.20198) 64-bit

Appendix B Passenger journey in 2035 flowchart (in A3 format)



EUROPEAN PARTNERSHIP
Co-funded by the European Union

Appendix C Passenger journey in 2050 flowchart (in A3 format)