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X-TEAM D2D Project: Designing and Validating a Concept of Operations for Door-To-Door Multimodal Transport

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Abstract: The project X-TEAM D2D (extended ATM for door-to-door travel) has been funded by SESAR JU in the framework of the research activities devoted to the investigation of integration of Air Traffic Management (ATM) and aviation into a wider transport system able to support the implementation of the door-to-door (D2D) travel concept. The project defines a concept for the seamless integration of ATM and Air Transport into an intermodal network, including other available transportation means, such as surface and waterways, to contribute to the 4 h door-to-door connectivity targeted by the European Commission in the ACARE SRIA FlightPath 2050 goals. In particular, the project focused on the design of a concept of operations for urban and extended urban (up to regional) integrated mobility, taking into account the evolution of transportation and passengers service scenarios for the next decades, according to baseline (2025), intermediate (2035) and final target (2050) time horizons. The designed ConOps encompassed both the transportation platforms integration concepts and the innovative seamless Mobility as a Service, integrating emerging technologies, such as Urban Air Mobility (e.g., electric vertical take-off and landing vehicles) and new mobility forms (e.g., micromobility vehicles) into the intermodal traffic network, including Air Traffic Management (ATM) and Unmanned Traffic Management (UTM). The developed concept has been evaluated against existing KPAs and KPIs, implementing both qualitative and quantitative performance assessment approaches, while also considering specific performance metrics related to transport integration efficiency from the passenger point of view, being the proposed solution designed to be centered around the passenger needs. The aim of this paper is to provide a description of the activities carried out in the project and to present at high level the related outcomes.

Keywords: multimodality; air traffic management (ATM); door-to-door (D2D) operations; urban air mobility (UAM); U-space; concept of operations (ConOps); intermodal transport; passenger experience; surface transport; simulation

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1. Introduction

In the future evolution of transport networks, Air Traffic Management (ATM) and Air Transport will be increasingly considered as a fundamental part of an intermodal transportation system, rather than standalone transportation means. The intermodal transport system has to be designed around the passenger's needs and in such a way to provide more transportation alternatives, which will be connected in a seamless integrated way. Based on that, the passenger's journeys will consist of a succession of different transport modes that have to be facilitated as seamless as possible, depending on the availability of individual transport modes, on a passenger's individual preferences regarding travel time, comfort, environmental impact and other criteria. Based on this driver, the ATM role needs to be redefined as part and maybe fulcrum of the intermodal system, in order to enable the possibility of optimization in near real time of the performance of the overall transportation system and to enable the possibility of performing a full door-to-door (D2D) journey, therefore leading to a paradigm shift from the optimization of the individual transportation means (i.e., of the individual legs of the journey) to the optimization of the overall journey.

The above indicated approach is coherent with the vision of the ACARE Flightpath 2050 [1] and is able to support the ACARE target to allow 90% of travelers within Europe to complete their door-to-door journey within 4 h, experiencing a seamless journey with full connectivity.

In this framework, the X-TEAM D2D (eXTEnded AtM for Door2Door travel) project has been funded by SESAR JU and started in the year 2020, carried out by a consortium including CIRA, as leader, ISSNOVA (with linked third party ISINNOVA), DLR, ILOT, D-Flight, and HVA (Amsterdam University of Applied Sciences).

The X-TEAM D2D project specific aim is the design of a Concept of Operations (ConOps) for ATM integration in an intermodal transport network serving urban and extended urban (up to regional) mobility, taking into account the transportation and passenger service scenarios envisaged for the next decades, according to a multi-layer incremental approach where the final target scenario refers to the long-term time horizon (2050) but also baseline (2025) and intermediate (2035) scenarios are carefully addressed. In addition, the project specifically addresses the integration in the overall system of the very important and emerging mobility form that exploits the vertical dimension of transport in urban and peri-urban environments, i.e., the Urban Air Mobility (UAM) [2]. In this framework, collaboration has also been established with the applicable running project ASSURED UAM (Acceptance, Safety and Sustainability Recommendations for Efficient Deployment of UAM) [3]. The complementarity of the two projects is in that ASSURED UAM is addressing the deployment of UAM in the European cities over the mid-term time horizon, also taking into account possible regulatory envisaged evolution [4]. From the practical point of view, with the aim of providing a specific contribution to particular operational scenarios, the project addresses the specific multimodal transport scenario of a passenger's D2D journey between a big metropolis, where a big hub airport is available, and a smaller city, served by a regional airport.

The project which designed target ConOps has been also preliminarily validated and evaluated against main applicable Key Performance Areas (KPA) and Key Performance Indicators (KPI), implementing both qualitative and, where possible, also quantitative performance assessment approaches.

In terms of study logic, the project first implemented dedicated studies to define future scenarios and use cases for the integration of the vertical transport with the surface transport towards integrated intermodal transport system and to identify the barriers towards this goal.

Then, the project carried out the design of an overall proposed ConOps, which has been organized into two main conceptual elements:

- The integration of ATM in intermodal transport infrastructure, devoted to the study of the integration of different transportation means at infrastructural level;
- The integration of ATM in intermodal service to passengers, devoted to design a unique service to passengers, i.e., to the studies for the integration of different transport services into unique service.

The project, finally, worked on the ConOps validation activities, by setting up the simulation framework and performing the simulation of the use cases deigned in the project, providing assessment and feedback on the designed concept for multimodal integrated D2D transport.

The overall methodology [5] for the deployment of the project activities in X-TEAM D2D is represented in the following Figure 1.

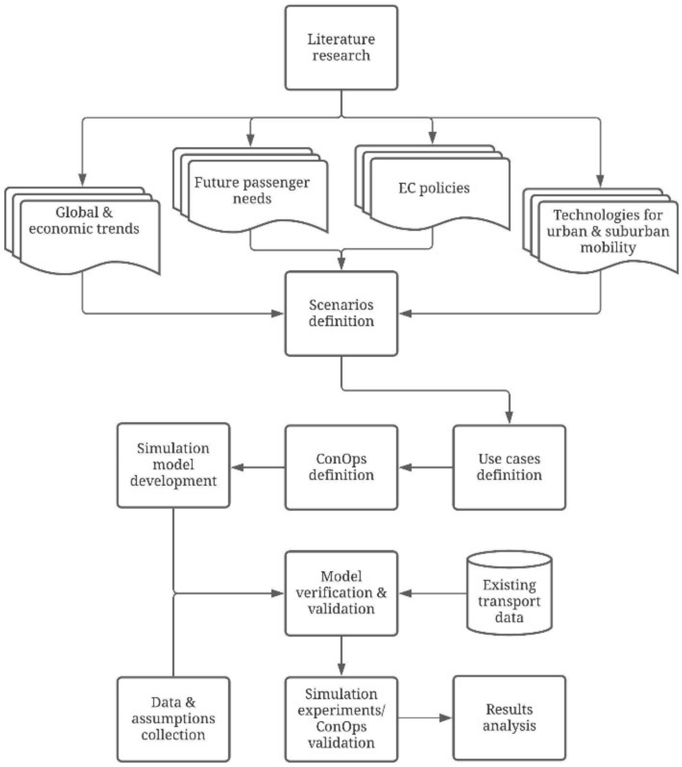

Figure 1. X-TEAM D2D methodology flowchart.

The activities that have been carried out in the project and the main related achievements are summarized at high level in this paper, which aims to present and inform about the X-TEAM D2D project. Due to the very wide scope of the project and the studies that have been carried out, the detailed provision of the project results is out of the scope of this paper, which indeed, as already indicated, aims to provide an overall project presentation to introduce future papers, providing the scientific details, and to guide the reader across the consultation of the detailed project deliverables that are publicly available on the project website [6].

It is worth noting here that the project results are based on the work performed by the project team starting from, and continuously considering, the results of the other researchers and projects addressing multimodality and establishing, and continuously maintaining, contacts with running international sibling projects, through dedicated multimodality workshops and synergy meetings. As it can be seen from the referenced project deliverables (all of them are publicly available on the specific page of the project website [7]), the project team carefully examined hundreds of documents from academia and projects and carried out critical analysis of them to derive inputs for the project work. For instance, the deliverable D2.1 "Future Reference scenarios and barriers" [8], which created the knowledge basis for the project activities' elaboration, carefully and critically examined more than 180 reference documents. Similar considerations apply to the other deliverables produced by the project, indicated here in the References' section. In total, hundreds of document and research outcome reports have been examined and considered by the project team.

Of course, such enormous amount of reference material, which guided the project team in performing the work, by properly having a foundation in well-established international research and in line with the effort already made by other researchers in the field, was impossible to be indicated in this paper's references. Therefore, the authors' choice was to indicate the project outcome documents as references only, where the readers can find specific references to the enormous amount of material examined.

2. Materials and Methods

2.1. Scenarios and Barriers Studies

The project activities have first been devoted to the definition and description of the expected scenarios in which future integrated metropolitan and regional transport would operate [8]. Specific studies have been carried out to investigate and define the future scenarios driving the implementation of a multimodal passenger transport system for door-to-door mobility and to identify the possible barriers to overcome.

The key results obtained by these studies have been the definition of urban and suburban mobility scenarios for multimodal transport, the identification of the most promising enabling technologies for multimodal transport in the near future as well as over the long term, the definition of the multimodal transport use cases, the identification of the main barriers that represent obstacles for the implementation of the envisaged scenarios and use cases. The added key result is the provision of detailed outcomes from the above outlined studies by specifically distinguishing the considerations related to baseline (2025), intermediate (2035) and final (2050) target time horizons.

In more detail, the key results obtained by the project in this domain are:

- The definition of the expected urban and suburban mobility reference scenarios according to 2025, 2035 and 2050 time horizons, considering global and regional economic trends, future passenger needs, EC policy and passenger experience, summarized by definition of three comprehensive scenarios definition environment for integrated transport development.
- The identification of the applicable technologies for urban and suburban mobility transport in the 2025, 2035 and 2050 time horizon, with reference to both the vertical and the surface ones as well as the ICT ones, indicating the most promising technologies from the perspective of integration into multimodal transport centered around ATM.
- The definition of a set of relevant use cases for the proposed ConOps assessment, which are based on the defined scenarios, on the prognosed future passengers' needs (defined passenger profiles) and on the technologies expected to be available in the considered time horizons. The result was a description of 18 use cases that were generated for three time horizons, for two passenger profiles and for three disruption scenarios.
- The identification and definition of barriers with respect to the integration of surface and vertical transport, based on the defined scenarios and identified technologies and related to both physical (hardware) and virtual dimension of transport integration process.

The results of the project activities addressing the definition of future scenarios for multimodal D2D passenger transport and associated barriers are reported in the X-TEAM D2D project deliverable D2.1 "Future Reference Scenarios and Barriers" [8].

Nevertheless, some relevant outcomes are summarized as follows:

- The main dominating trend in technology development is increasingly relying on data, with more accurate, near real-time information. The same can be observed with regard to transport where beside technological progress (i.e., in engine fuel consumption efficiency) the room for improvement is seen in operation management through the use of mentioned data and considering issues on a higher level, as integrated with surrounding elements.
- The main barriers against 2D and air transport integration are related to the following:
  - New hardware technologies entering the market (e.g., UAM);
  - Digital technology definitions and implementation;
  - Interface with end users (i.e., passengers).

  In more detail, in terms of barriers for the implementation of the X-TEAM D2D defined use cases into real situations in the future, four groups of barriers were identified and some potential enablers to overcome such barriers have been proposed, as outlined in the following:

- Policy and strategy planning: related barriers dealing with question marks commonly attached to the numerous aspects related to the process of implementation of defined solutions. They all have to be solved before initiation of complex and effortful investment such as deployment of necessary infrastructure for electric cars or Urban Air Mobility.
- Digitalization: it is a fundamental enabler for the exchange of information. The data must be available. It leads to the requirement of cost investment and upgrading of current management systems (such as in case of a local railroad transport network). In addition, dedicated standards and recommendations, as well as regulation covering future data collecting, processing and sharing, have to be defined. The digitalization should cover not only transport but also regulations enabling future high-level management of the complex transport ecosystem (algorithmic governance).
- Hardware technology availability: development of solutions enabling safe, reliable and efficient operation of autonomous vehicles, passenger unmanned drones (eVTOLs) and necessary ground infrastructure in changing and increasingly more demanding natural conditions. It is considered as determined by the development of dedicated, adequate standards for new mobilities.
- Unconstrained data collecting, processing and sharing: data are the main determinant of the future transport integration process. Addressing the standards and recommendations for the exchange of real-time data between operators and all interested parties is very important. The definition of rules of using private data is critical for the success of enabling demand forecasting.

Based on the identified barriers, the main technological enablers supporting the integration of the different transportation alternatives into unique multimodal mobility services have been identified, as summarized in Figure 2.

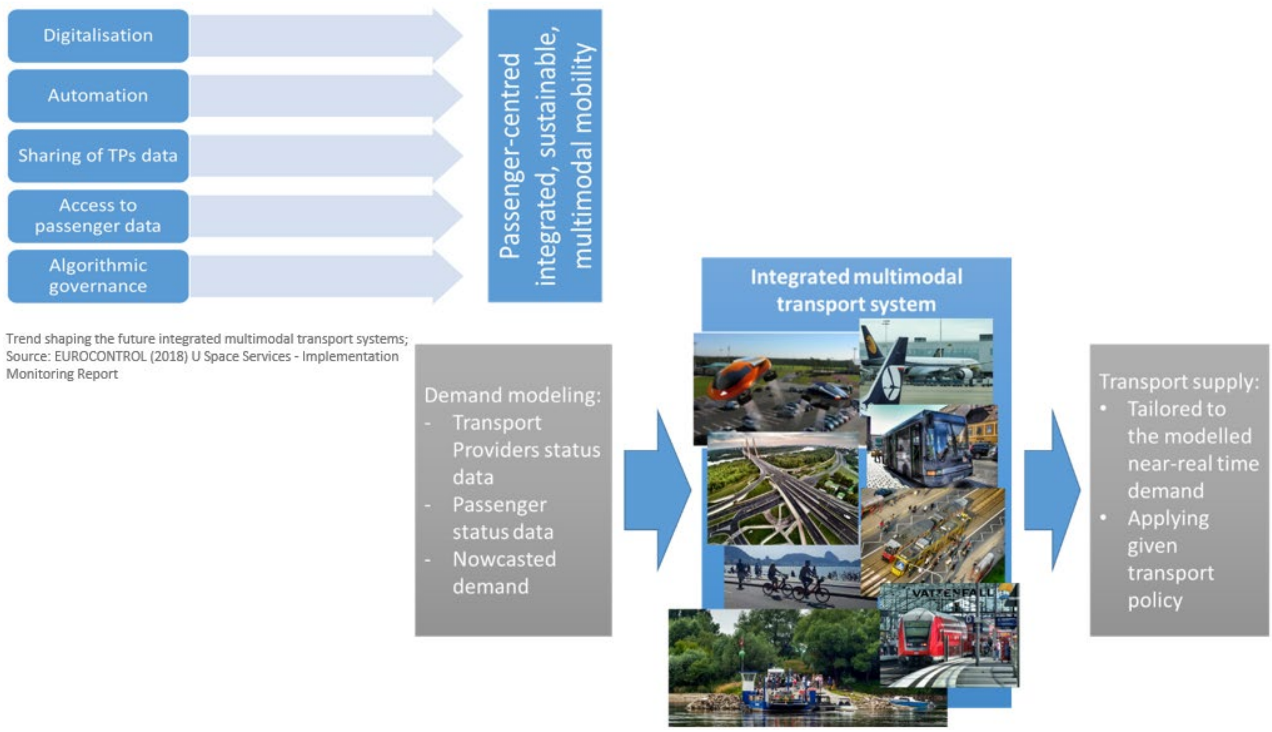

Figure 2. Technological enablers for integrated mobility service.

Specific details on the analysis of barriers against multimodal transport implementation carried out in the X-TEAM D2D project can be found in [9].

2.2. Integration of ATM in Intermodal Transport Infrastructure

The project carried out dedicated studies addressing the integration of the multiple available transportation means, including ATM and aviation as well as U-space and Urban Air Mobility, into unique integrated physical infrastructure. The study considered both the available and the perspective transport means, with reference to surface (ground, water) and vertical mobility, as summarized in Figure 3.

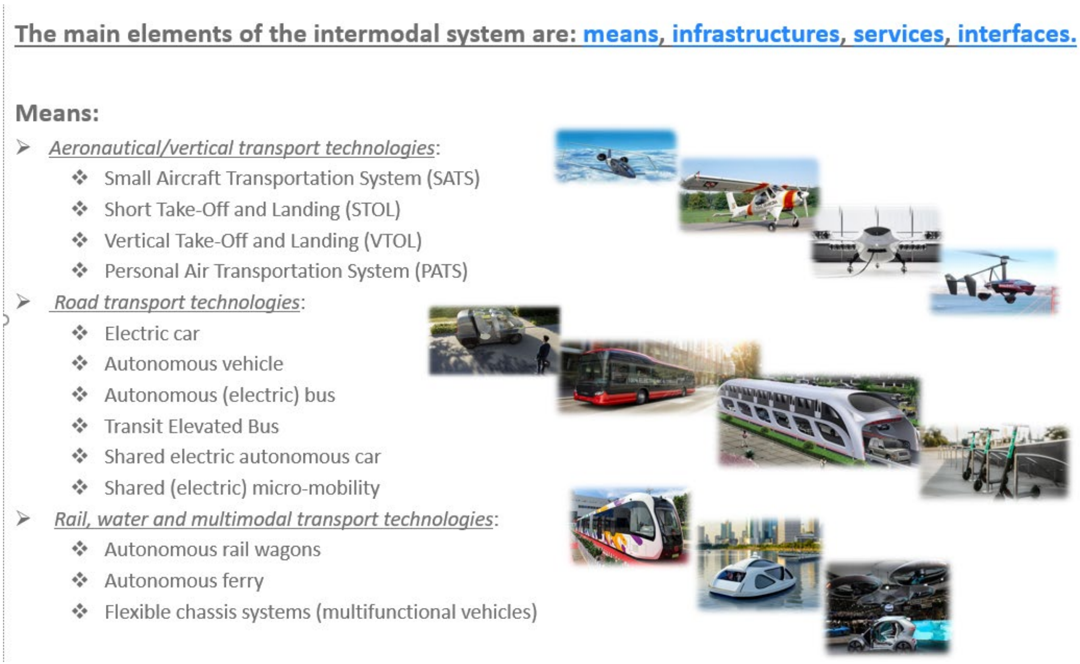

Figure 3. Transportation means in vertical and surface transport.

The key results of the performed studies in this domain consisted of the identification of technological enablers for such physical integration among surface and air transportation means over different time horizons, in the design of a dedicated ConOps for the integrated transport network, in the design of dedicated service blueprint modeling the whole D2D journey and interaction of the passengers with the infrastructure and in the definition of the needed organizational and policy steps for the transition from the current situation towards the integrated X-TEAM D2D defined infrastructure.

In more detail, the key results obtained by the project in this domain are:

- The detailed identification of technological enablers for the ATM and air transport integration in the overall intermodal transport system, in terms of available transportation means alternatives and of future perspective available transportation means that can enable the integration of different means into a unique multimodal network centered in ATM and air segment, considering requirements and constraints of each component. The technological enablers have been identified in terms of enablers for digitalization barriers and enablers for technological barriers.
- The definition of the objectives of the integrated intermodal system, the design of the high-level intermodal system architecture, where the associated structure is envisaged and the main elements are identified, the definition of the role that ATM and UTM play in the intermodal system over the three considered time horizons (final 2050, baseline 2025 and intermediate 2035), emphasizing that the UTM role will increasingly become relevant up to the final time horizon even if not yet relevant enough in the baseline time horizon.

- The identification of high-level requirements for the integration of different transport infrastructures into a unique network, from both the perspective of the user and of the system.
- A detailed definition of the service blueprint for the X-TEAM D2D designed multi-modal transport system, with reference to all the use cases designed in the project.
- The identification of needed policy and organizational actions for evolutionary change management from the current fragmented transport situation to an X-TEAM D2D proposed intermodal transport ConOps.

The results of the project activities addressing the studies about extended ATM-intermodal integration and connection ConOps design are reported in the X-TEAM D2D project deliverables D3.1 "Concept of Operations for ATM integration in intermodal transport system [Concept Outline]" [10] and D3.2 "Concept of Operations for ATM integration in intermodal transport system [Concept Description]" [11].

Nevertheless, some relevant considerations emerging from the studies are worth summary as follows:

- As unmanned and autopilot operations continue to multiply, ATM systems will need to move to a more scalable model: a digital system that can monitor and manage increased activity. This system is the well-known Unmanned Traffic Management (UTM), i.e., a networked collection of services provided by U-Space, envisaged to be interoperable and consistent with existing ATM systems in order to facilitate safe, efficient and scalable operations.
- Passengers must be guaranteed travels that use the different technologies between air, sea and land, in the most transparent possible way and this means that five key aspects are addressed toward integration: physical side, networks, fares, information and institutions.
- In terms of infrastructure integration over the 2025 time horizon, it will be very important, already at present, to monitor and safeguard the effective use of existing urban infrastructure to better serve intermodal transportation development and design and certify vertipads (necessary for vehicle take-off and landing) that integrate positively with existing urban infrastructure. Furthermore, it will already be needed to start actions aimed to promote connecting hub airports with one or two regional airports (point-to-point connections executed by low-cost carriers) and connecting the hub airport with the city by numerous modes (trains, bus, taxi, etc.). The same considerations, even if to a lesser extent, apply also to regional airports.
- In terms of infrastructure integration over the 2035 time horizon, efforts made in the infrastructure sector will have to consider an ever-greater optimization. In particular, it will be very important to support a broader urban planning capability that relies on extensive collaboration with local ecosystems that build and live in the urban context and to create solutions that adhere to the principles of functional compactness, which aims to enhance the value of transport infrastructure and adapt its use for future mobility. Due to increased technology development, users' focus will be on personal needs as well as impact on environment, so resulting in the following assumptions: relevant percentage of cars available on roads will be electric; driving performances will by highly automated; car sharing model will be dominating in urban areas; UAM for passenger transport in experimental sites will be available in Europe but without significant impact on mobility in metropolitan areas; hub airports will be connected with the city by numerous modes and regional airports and will provide access to more than one form of public transport service.
- In terms of infrastructure integration over the 2050 time horizon, automation, electrification, connectivity and telematic services will simplify the relationships between transportation means, users and surrounding environment, requiring an innovative rethinking of infrastructures: digital solutions will be developed that will help entities and operators to leverage the new technologies in managing future smart cities. Resulting assumptions are that: all cars approved on roads will be electric, mostly highly

automated and autonomous; in urban areas, a car sharing model will be dominating; short range airlines connections operated by zero emission aircraft will remain the air mode of transport with highest potential to impact efficiency of the transport system; UAM dedicated to passenger transport will be available in Europe offering direct access to densely populated city areas; hub airports will be connected with the city by numerous collective, autonomous transport modes and regional airports will provide access to more than one collective autonomous transport service.

2.3. Integration of ATM in Intermodal Service to Passengers

Starting from the studies carried out about the definition of future scenarios and use cases and taking into account the parallel studies about the infrastructural integration of different transport means and of ATM and UTM into unique multimodal transport networks, the X-TEAM D2D project carried out dedicated studies addressing the integration of the services to passengers. Such studies started from the current situation, where basically each leg of the journey has its own service to passenger, towards unique passengers' service for the whole D2D journey. Such studies led to the formulation of X-TEAM D2D ConOps for Total Traffic Management (TTM), which contains management and service applications that should pave the way to TTM for all modes of transport in which the travelers' preferences have a high priority.

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.

In 2025, the implementation of electric vertical take-off and landing aircrafts (eVTOL) for UAM operation will take place as an experimental initial form of mobility. 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 Mobility as a Service (MaaS) activities, e.g., single ticket, pricing by optimizing 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 level of difficulty to integrate the ATM and U-Space system.

Time 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 communication coverage for all stakeholders (including the pilot) by implementing current and new communications and surveillance infrastructure (e.g., new cooperative surveillance technology).

For the 2050 time horizon, intermodal travel is characterized 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 the 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, sand trategic 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.

MaaS will be possible for every traveler for door-to-door travel, including flight segment. The optimal configuration of the ConOps with all their management systems, instruments and applications as an extended ATM operating concept for passenger services is represented in Figure 4, as outlined in [12].

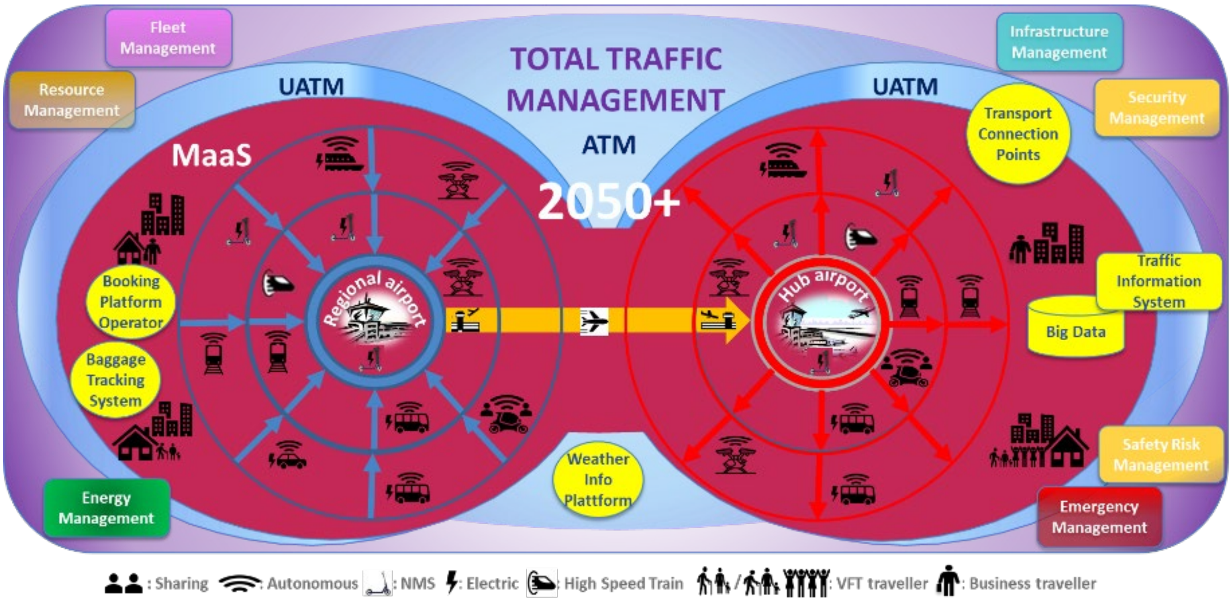

Figure 4. X-TEAM D2D Total Traffic Management concept for 2050 and beyond [13,14].

The results of the project activities addressing the studies about extended ATM-intermodal integration and connection ConOps design are reported in the X-TEAM D2D project deliverables D4.1 "Concept of Operations for ATM service to passengers in inter-modal transport system [Concept Outline]" [13] and D4.2 "Concept of Operations for ATM service to passengers in intermodal transport system [Concept Description]" [14].

Nevertheless, some relevant lessons learned in this domain are outlined in the following:

- The Total Traffic Management system will be composed of many traffic management systems and will constitute a complex overall system. Therefore, in the perspective of 2050 and a further time horizon, the artificial intelligence (AI) component will be necessary for the operational concept of the ATM service for passengers in intermodal transport. It means not only the development of autonomous means of transport but also the implementation and control of inter- and multimodular networked management systems. The mobility of the future will be digitally networked and will provide individual, tailor-made mobility service offers. Artificial intelligence (AI) can make an important contribution here, on the one hand by being able to relieve infrastructure, the environment and resources in a sustainable and efficient way, and on the other by guiding travelers to their destinations in a time-saving and flexible manner.
- 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 (Single European Sky ATM Research), 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.
- 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.
- Most users will expect a comparatively seamless mobility experience on the ground, water, and air. To deliver this experience, providers and agencies will need to offer and implement an efficient Mobility as a Service that can integrate all available modes of transportation.
- The fleet management must ensure that all vehicles within the integrated system and the integrated providers are used economically and that sufficient transport capacity is available for all processes.

3. Results

For the validation of formulated ConOps, the X-TEAM D2D project has developed a simulation framework, including mainly two components: the door-to-airport and the airport-to-door phases of the passenger journey. The simulation framework has been implemented through a discrete event simulation software [15,16].

The validation was composed of different stages. Due to the visionary nature of the scenarios, first a plausibility validation was performed, which consisted of interaction with the project appointed advisory board to verify that the scenarios and approach were reasonable and plausible. Then, after obtaining the plausibility validation, the project team performed the next stage, which consisted of the framework verification and validation (VV), consisting of a bottom-up approach by independently verifying and validating the different elements of the framework (vehicles, network dimensions, elements performances, etc.) against public information like Google, Open Street Maps, national transport services and manufacturers information, among others. Once all the elements were VV, the complete D2D trajectory was considered plausible, verified, and validated to the extent possible with the current state of practice. Then, the project team implemented into the simulation framework the designed 18 scenarios that progressively integrated the most relevant elements of the ConOps and ran several replications with each scenario, to address the inherent variability of the system.

In each considered time horizon, business and VFR (visiting friends and relatives) 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 the passengers' journey for each scenario can be found in the deliverable D2.1 "Future Reference Scenarios and Barriers" [8].

In more detail, 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. Each experimental scenario simulated 24 h of passengers traveling 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: Profile B—A business traveler 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 better capture the D2D system behavior.

The KPIs evaluation are the main results extracted from the framework considering only a limited amount of the potential KPIs from the KPAs considered in the project; this is due to the resolution level developed in the framework; a complete detailed analysis of the considered KPAs and KPIs is reported in the project deliverable D5.1 "Concept of Operations Validation report" [17].

The goal of the developed simulation framework was to evaluate the effectiveness and performances of the proposed future concepts of operations on the passenger journey in 2025, 2035 and 2050 time horizons. Based on the multilayer approach implemented in the ConOps in terms of addressed time horizons, the simulation framework was also built based on a multilayer approach. Under such approach, first the existing transportation network was created and verified and then, future transport technologies were added to the model considering corresponding time horizon assumptions and ConOps. The approach for ConOps validation implemented in the project is represented in the following Figure 5.

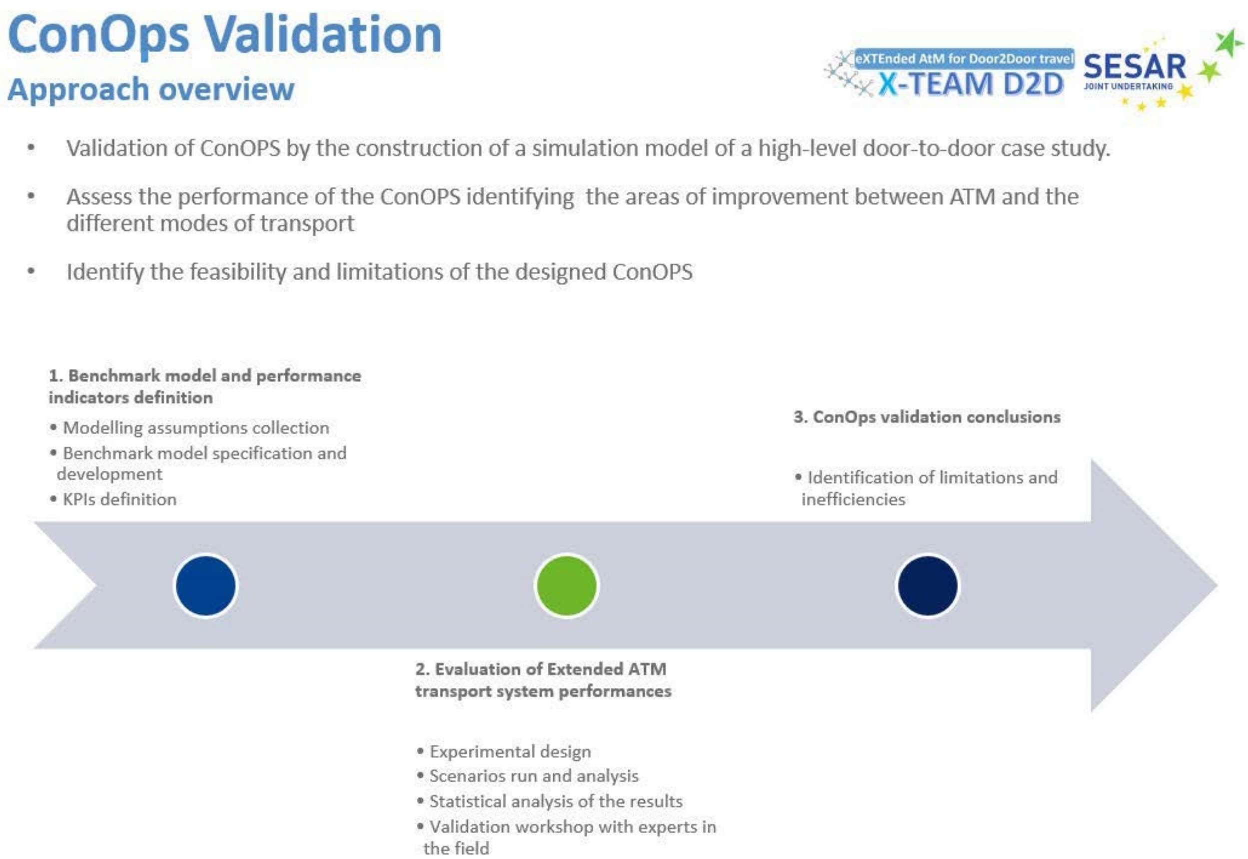

Figure 5. X-TEAM D2D approach to ConOps validation.

The framework consists of three groups of elements:

- The dynamic entities, representing passengers and vehicles transporting passengers from their origin to the airport;
- The static elements, representing transport stations serving as passengers' entry, transfer and exit points, with a fixed position for the interconnected multimodal transport networks;
- The nodes and edges connected into a network that vehicles and passengers use to move through the space between transport stations.

Figure 6 [12] shows a part of the simulation model representing door-to-airport journey.

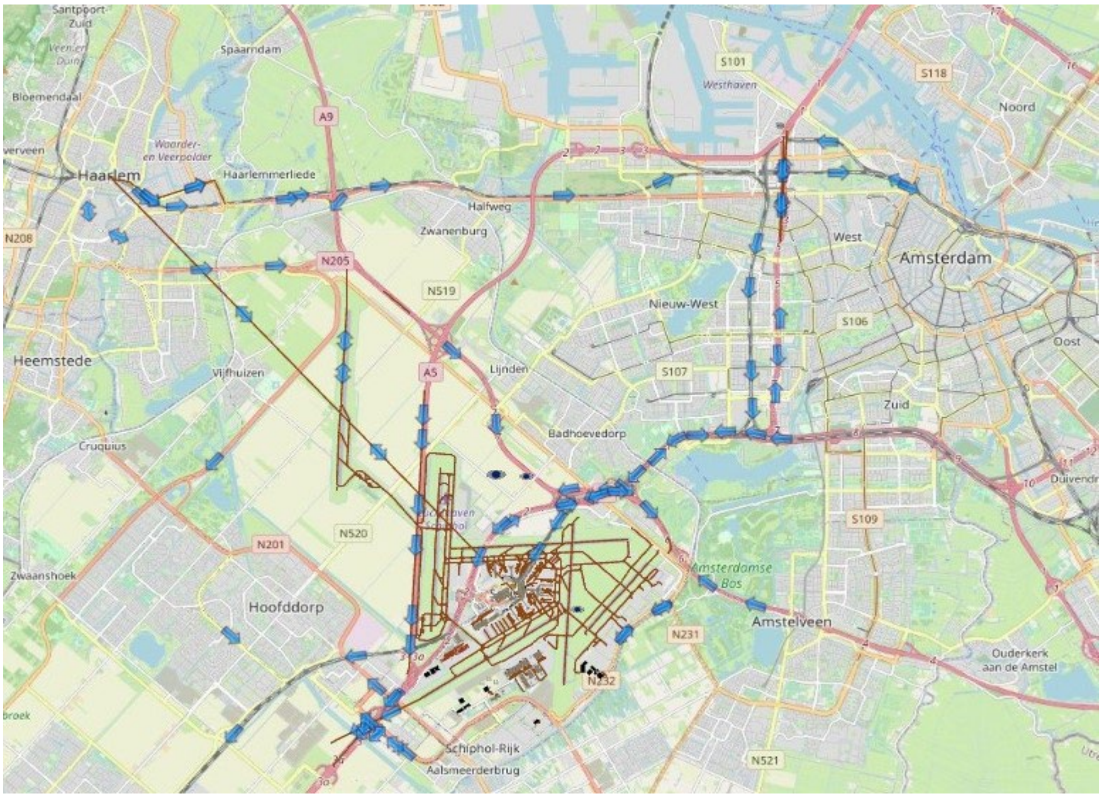

Figure 6. Door-to-airport part of the X-TEAM D2D simulation model [17].

In the model, the arrival of passengers and most of the transportation means are generated stochastically based on the assumptions gathered from public transport information sources. Some transport means (such as buses and trains) are generated according to a schedule, as observed in real-life operations.

A series of simulation experiments has been run using the developed framework to validate the defined ConOps. These experiments consisted of multiple runs according to the different scenarios defined in the project in order to characterize passenger travel in 2025, 2035 and 2050 under normal conditions, ad-hoc disturbance in one of the modes and disturbance in one of the modes five hours prior to the departure of the passengers.

For each run simulating one day, a series of indicators have been tracked to evaluate the performance of ConOps in each scenario, including total travel time and total travel distance, as summarized in the following Figure 7.

Some preliminary results from the ConOps validation activities have been provided in the previous conference paper [5], where some scenarios referred to the 2025 and to the 2035 time horizon were considered, considering nominal situations, i.e., without disruptions, and situations where disruptions affected the transportation system.

Based on the preliminary results presented in [5], business travelers are expected to have significant benefits in travel time and distance if new technologies such as electric scooters and eVTOL are introduced into transportation networks. Nevertheless, if the existing road infrastructure and its speed limitations remain unchanged up to 2035, the improvement of travel times will be lost for business passengers who encounter disruptions on their way to the airport. The latter means that not only technological and IT advancements are required for the improvement of passenger travel, but a system-wide redesign of the transportation network and consideration of potential inefficiencies in the concepts of future transport operations are needed.

Nr	KPA	KPI	Measurement	Comments
1	D2D journey efficiency	Total distance travelled	Door-to-door for each PAX	measured for each PAX
2		Total travel time	Door-to-door for each PAX	measured for each PAX
3		Average travel speed	KPI 1/ KPI 2	measured for each PAX
4	D2D journey quality	Waiting time at interconnections	Access-egress time/total travel time	measured for each PAX
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
6		Accessibility of wayside infrastructures	Number of architectural barriers encountered/number of obstacles	
7	System resilience	Response time to service interruptions	Average to restore the service/average	measured per operating line by the mode operator
8	Technology impact on D2D journey	Travel distance improvement	Average per scenario 1/ average per scenario 2	
9		Travel time improvement	Average per scenario 1/ average per scenario 2	
10	D2D journey structure	Number of modes included in a single ticket	Number of tickets/number of modes	
11		Number and modes used	Recording name of each mode used per PAX in D2D	measured for each PAX
12	Financial	Total cost of travel	EURO/PAX	measured for each PAX
13	Journey efficiency (from Provider point of view)		Utilization Rate	Measured for Vehicles used

Figure 7. Key Performance Areas (KPAs) and Key Performance Indicators (KPIs) considered in X-TEAM D2D ConOps validation.

The results here outlined are preliminary and have been obtained during the project execution, as already presented in previous works. More detailed presentation of the validation activities carried out in the project and of the related results analysis is provided in the X-TEAM D2D project deliverable D5.1 "Concept of Operations Validation report" [17] and will be provided in future papers.

4. Conclusions

This paper outlined the scope of the X-TEAM D2D project and summarized the activities carried out in the project and its related achievements. In particular, the paper first addressed the description of the studies performed, and the related outcomes, about the definition of future scenarios and use cases for the integration of vertical transport with the use of surface transport towards an integrated intermodal transport system and the identification of the resulting barriers. Then, the paper reported the main activities and concepts related to the project activities addressing the integration of ATM in intermodal transport infrastructure and the integration of ATM in intermodal service to passengers. Finally, the paper summarized the approach implemented in the project for the proposed ConOps validation through numerical simulations and provided a reminder of the preliminary results, waiting for the provision of final results and more detailed analysis in future papers. The main aim of the paper was to provide an overall X-TEAM D2D project presentation in order to constitute a reference for future papers, which will provide the scientific details, and to guide the reader across the consultation of the detailed project deliverables that are publicly available on the project website.

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References

1. European Commission. Directorate-General for Mobility and Transport, Directorate-General for Research and Innovation, Flightpath 2050. Europe's vision for aviation: Maintaining global leadership and serving society's needs. Publications Office. 2012. Available online: https://data.europa.eu/doi/10.2777/15458 (accessed on 10 January 2023).
2. Menichino, A.; Di Vito, V.; Dziugiel, B.; Liberacki, A.; Hesselink, H.; Giannuzzi, M. Urban Air Mobility Perspectives over Mid-Term Time Horizon: Main Enabling Technologies and Readiness Review. In Proceedings of the IEEE ICNS 2022 Hybrid Conference, Herndon, VA, USA, 5–7 April 2022.
3. Dziugieł, B.; Mazur, A.; Stanczyk, A.; Maczka, M.; Liberacki, A.; Di Vito, V.; Melo, S.; ten Thije, J.; Hesselink, H.; Vreeken, J.; et al. Acceptance, Safety and Sustainability Recommendations for Efficient Deployment of UAM. In *Materials Science and Engineering*; IOP: Bristol, England, 2022; p. 012082.
4. Mazur, A.M.; ten Thije, J.; Vreeken, J.; Hesselink, H.; Dziugieł, B.; Wyka, S.; Liberacki, A.; Idzikowska, T.; Stanczyk, A.D.; Utracka, A.; et al. Regulatory framework on the UAM operational concepts of the ASSURED-UAM project. *Aircr. Eng. Aerosp. Technol.* **2022**. ahead-of-print. [CrossRef]
5. Bagamanova, M.; Mujica Mota, M.; Di Vito, V.; Montaquila, R.V.; Cerasuolo, G.; Dziugieł, B.; Maczka, M.; Meincke, P.A.; Duca, G.; Russo, R.; et al. Extended ATM for Seamless Travel (X-TEAM D2D). In Proceedings of the First SIMS (Scandinavian Simulation Society) EUROSIM Conference on Modelling and Simulation, SIMS EUROSIM 2021, Virtual, 21–23 September 2021.
6. Available online: http://xteamd2d.eu/ (accessed on 10 January 2023).
7. Available online: http://xteamd2d.eu/deliverables/ (accessed on 10 January 2023).
8. X-TEAM D2D Consortium. D2.1–Future Reference Scenarios and Barriers. 2021. Available online: https://xteamd2d.eu/future-reference-scenarios-and-barriers/ (accessed on 10 January 2023).
9. Dziugieł, B.; Mazur, A.; Liberacki, A.; Ginter, P.; Utracka, A.; Wyka, S.; Di Vito, V.; Menichino, A. Multimodal 3D transport system implementation barriers in populated municipalities. Submitted for publication on Aircraft Engineering and Aerospace Technology (AEAT) journal and under review. AEAT-10–2022–0286.
10. X-TEAM D2D Consortium. D3.1–Concept of Operations for ATM Integration in Intermodal Transport System [Concept Outline]. 2021. Available online: https://xteamd2d.eu/wp-content/uploads/2022/03/X-TEAM-D2D_D3.1_Concept-of-Operations-for-ATM-Integration-in-Intermodal-Transport-System_v1.0-Submitted.pdf (accessed on 10 January 2023).
11. X-TEAM D2D Consortium. D3.2–Concept of Operations for ATM Integration in Intermodal Transport System [Concept Description]. 2022. Available online: http://xteamd2d.eu/concept-of-operations-for-atm-integration-in-intermodal-transport-system-concept-description/ (accessed on 10 January 2023).
12. Di Vito, V.; Montaquila, R.V.; Cerasuolo, G.; Dziugieł, B.; Maczka, M.; Mazur, A.; Meincke, P.A.; Naser, F.; Mujica Mota, M.; Bagamanova, M.; et al. An outline of a Concept of Operations for integration of ATM and air transport into multimodal transport system for Door-to-Door travel. In Proceedings of the IEEE ICNS 2022 Hybrid Conference, Herndon, VA, USA, 5–7 April 2022.
13. X-TEAM D2D Consortium. D4.1–Concept of Operations for ATM Service to Passengers in Intermodal Transport System [Concept Outline]. 2021. Available online: https://xteamd2d.eu/wp-content/uploads/2022/03/Submitted-X-TEAM-D2D_D4.1_Concept-of-Operations-for-ATM-service-to-passengers_v1.0.pdf (accessed on 10 January 2023).
14. X-TEAM D2D Consortium. D4.2–Concept of Operations for ATM Service to Passengers in Intermodal Transport System [Concept Description]. 2022. Available online: http://xteamd2d.eu/concept-of-operations-for-atm-service-to-passengers-in-intermodal-transport-system-concept-description/ (accessed on 10 January 2023).
15. Bagamanova, M.; Mujica Mota, M.; Di Vito, V. X-TEAM D2D: Modeling Future Smart and Seamless Travel in Europe. In Proceedings of the Winter Simulation Conference 2021 "Simulation for a Smart World: From Smart Devices to Smart Cities", Phoenix, AZ, USA and Virtual, 13–15 December 2021.
16. Bagamanova, M.; Mujica Mota, M.; Di Vito, V. Exploring the Efficiency of Future Multimodal Networks: A Door-to-Door Case in Europe. *Sustainability* **2022**, *14*, 13621. [CrossRef]
17. X-TEAM D2D Consortium. D5.1–Concept of Operations Validation Report. 2022. Available online: http://xteamd2d.eu/concept-of-operations-validation-report/ (accessed on 10 January 2023).