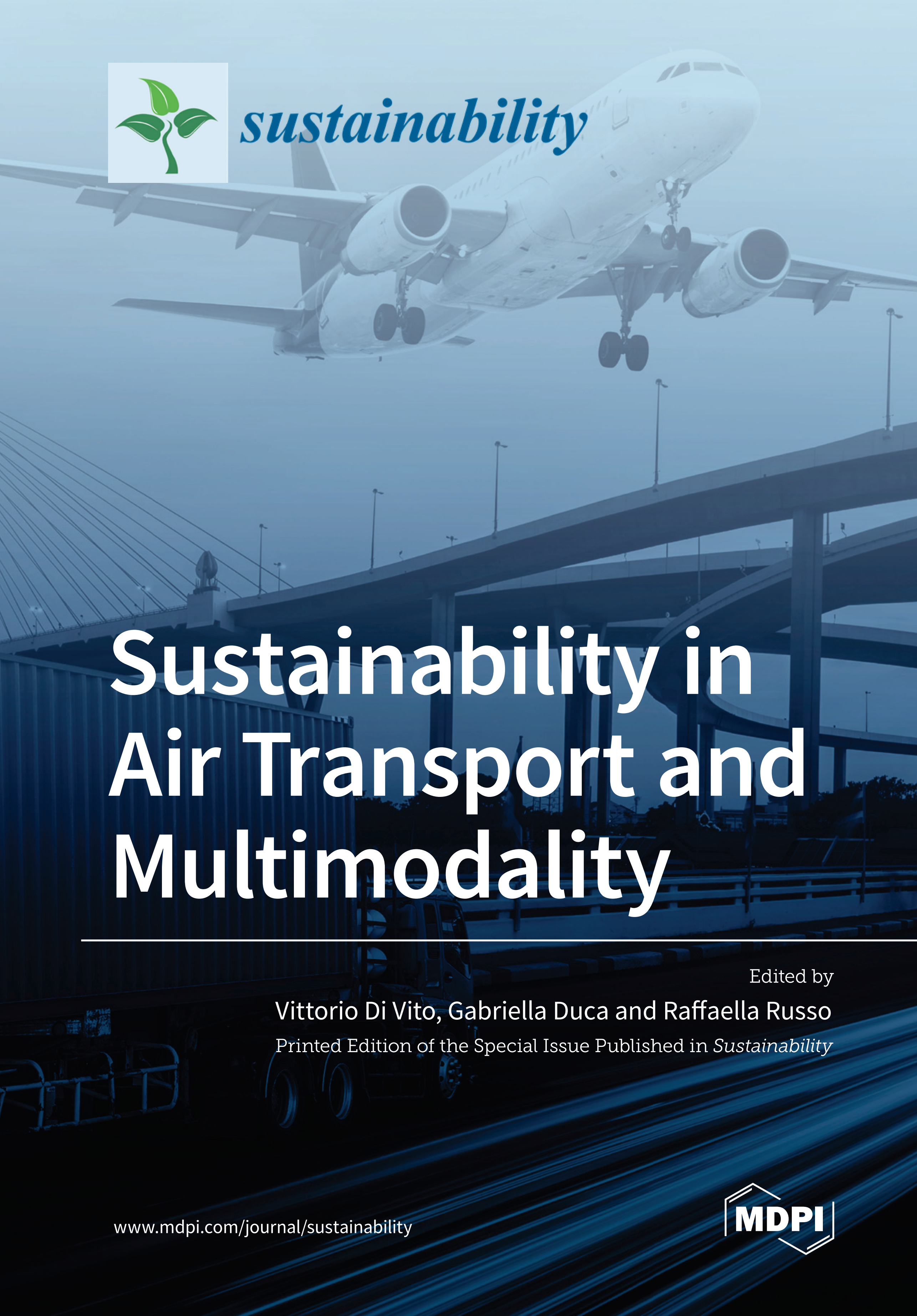

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Sustainability in Air Transport and Multimodality

Edited by

Vittorio Di Vito, Gabriella Duca and Raffaella Russo

Printed Edition of the Special Issue Published in *Sustainability*

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This is a reprint of articles from the Special Issue published online in the open access journal *Sustainability* (ISSN 2071-1050) (available at: https://www.mdpi.com/journal/sustainability/special_issues/Air_Transport_Multimodality).

For citation purposes, cite each article independently as indicated on the article page online and as indicated below:

LastName, A.A.; LastName, B.B.; LastName, C.C. Article Title. *Journal Name* **Year**, *Volume Number*, Page Range.

ISBN 978-3-0365-7102-7 (Hbk)
ISBN 978-3-0365-7103-4 (PDF)

Cover image courtesy of ISSNOVA—Institute for Sustainable Society and Innovation.

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About the Editors

Vittorio Di Vito

Vittorio Di Vito, Ph.D., is the head of the CIRA (Italian Aerospace Research Center) Air Traffic Efficiency Dept. (since 2015). He was previously Senior Researcher and System Engineer in CIRA in the Air Traffic Management Dept. (2009–2014), and Research Engineer in the CIRA Flight Systems Dept. (2004–2008). His research and development activities are in the fields of Air Traffic Management (ATM); Urban Air Mobility (UAM); multimodality in transport, aviation sustainability, Detect and Avoid (DAA), and surveillance systems; autonomous flight systems development; and aviation operations and aircraft trajectory optimization. He served as Consortium Manager of the project X-TEAM D2D (Extended ATM for Door-to-Door travel) funded by the European Commission SESAR JU, which supported the preparation of this book. He works in several international projects, with coordination as well as technical leadership roles, addressing both fundamental research and applications development, up to flight demonstration, in the fields of Urban Air Mobility, Flight Management Systems, Conflict Detection and Resolution, trajectory optimization, and decision-making support systems, for applications in both manned and unmanned aircraft and drones as well as for ground-based aerial traffic management. He is the author of more than 80 papers, in journals and conference proceedings, and is an Associate Editor (since 2016) and Editorial Board Member (since 2014) of the *SAGE Journal of Aerospace Engineering*. He previously carried out research activities in the field of Power Systems analysis and optimization at the University of Cassino and Southern Lazio (Italy), Industrial Engineering Dept., where he received his Ph.D. in Electrical and Information Engineering (2005) and his cum laude master's degree in Electrical Engineering (2001).

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Raffaella Russo

Raffaella Russo, M.Sc. in Economics and Finance, is a Senior Scientist and Senior Project Manager at ISSNOVA (2019–current), where she leads the Knowledge Transfer Lab. She worked for several institutions, such as AMRA scarl (2011–2018), where she supported the coordination of several H2020 and FP7 projects, contributing in the field of cost and benefits analysis connected with the exploitation of conventional and unconventional energy sources, and in the identification of key factors underpinning risk perception. Raffaella is also a consultant for the University of Salerno (2018–current). Raffaella's current research analyses are mainly devoted to developing indicators to measure the social and economic impact of some hazardous events and to the identification of socio-economic barriers to systems resilience. Presently, she is involved in several European and Italian projects, where her expertise is mainly focused on socioeconomic stressors, social aspects of trust, social acceptance, and in the identification of the socio-economic impact related to the deployment of new technologies in different fields. Furthermore, she is interested in the transport sector, with a special focus on sustainability and on the promotion of passengers' inclusiveness.

Preface to "Sustainability in Air Transport and Multimodality"

This book addresses fundamental research results in the framework of integrating different transport modes into a unique mobility infrastructure and service allowing for multimodal choices for passengers in their journey and increasing the sustainability of mobility as a whole.

The addressed topic has been of relevant importance in recent years, given the increasing attention that is devoted to sustainability aspects in aviation and to the emerging need to achieve multimodality in transportation by integrating the vertical dimension with the horizontal one, particularly in urban and peri-urban environments. The research community is considering new technologies and concepts regarding the implementation of seamless door-to-door travel, which requires the implementation of fully integrated intermodal transport systems, allowing passengers easy and seamless transfer between different transport modes, where Air Traffic Management (ATM) and air transport can play a fundamental role. In this framework, the new paradigm in transport is the one of shifting from the optimization of the individual transport segments (such as aviation and ATM, for instance) of the journey to the optimization of the overall journey, including all the possible transportation means that allow for achieving, in combination and with multimodal possible choice, a unique seamless door-to-door journey for different categories of passengers and in accordance with their preferences.

Through such a new global optimization paradigm, it will be possible to increase the efficiency of the overall transport chain by improving the interoperability of the different modes of transport, while simultaneously increasing environmental, social, and economic sustainability, whose complementary implications are of the utmost importance today and will become increasingly fundamental in the future, prompting a more efficient use of existing and future infrastructure.

Vittorio Di Vito, Gabriella Duca, and Raffaella Russo
Editors

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Concept Paper

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

Vittorio Di Vito [1,*], Roberto Valentino Montaquila [1], Giovanni Cerasuolo [1], Bartosz Dziugieł [2], Maciej Maczka [2], Anna Mazur [2], Peter A. Meincke [3], Fares Naser [3], Miguel Mujica Mota [4], Margarita Bagamanova [4], Abdel el Makhloufi [4], Gabriella Duca [5], Raffaella Russo [5], Luigi Brucculeri [6] and Stefano Proietti [7]

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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

Citation: 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. X-TEAM D2D Project: Designing and Validating a Concept of Operations for Door-To-Door Multimodal Transport. *Sustainability* **2023**, *15*, 2380. https://doi.org/10.3390/su15032380

Academic Editor: Armando Cartenì

Received: 29 July 2022
Revised: 10 January 2023
Accepted: 13 January 2023
Published: 28 January 2023

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.

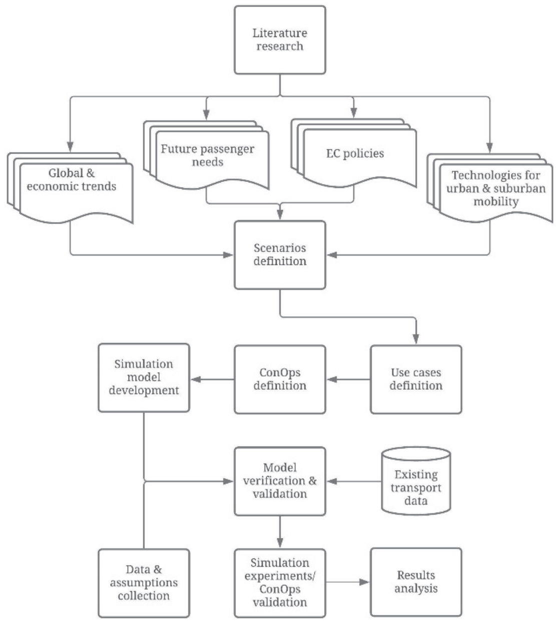

Figure 1. X-TEAM D2D methodology flowchart.

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.

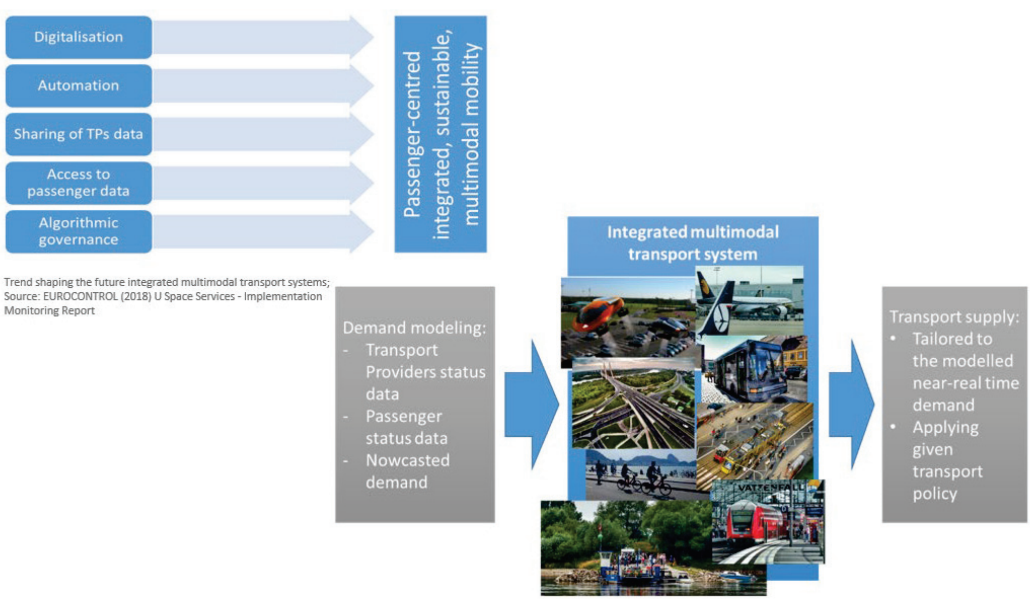

Figure 2. Technological enablers for integrated mobility service.

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.

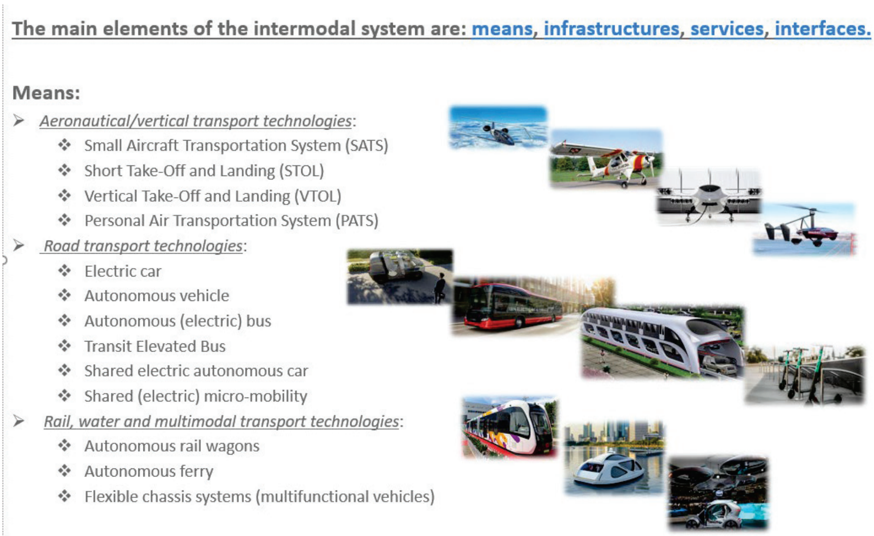

Figure 3. Transportation means in vertical and surface transport.

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].

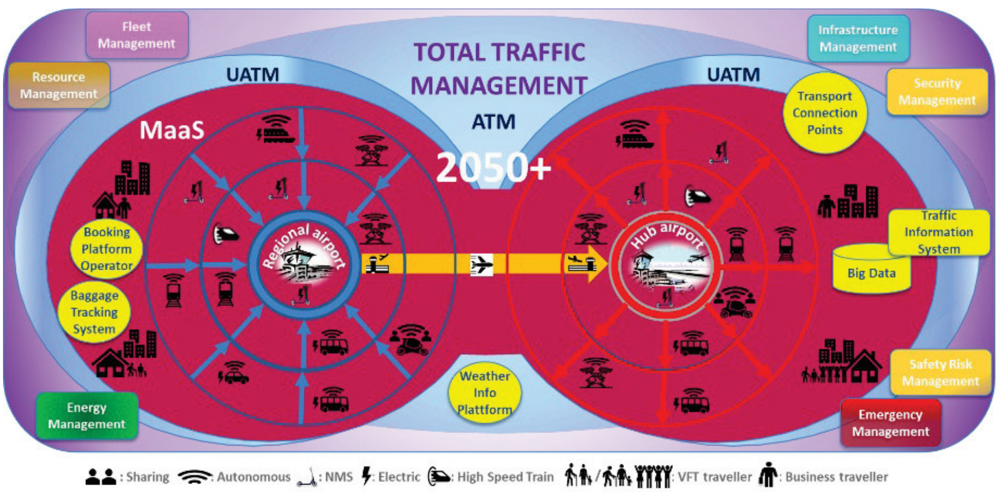

Figure 4. X-TEAM D2D Total Traffic Management concept for 2050 and beyond [13,14].

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 intermodal 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.

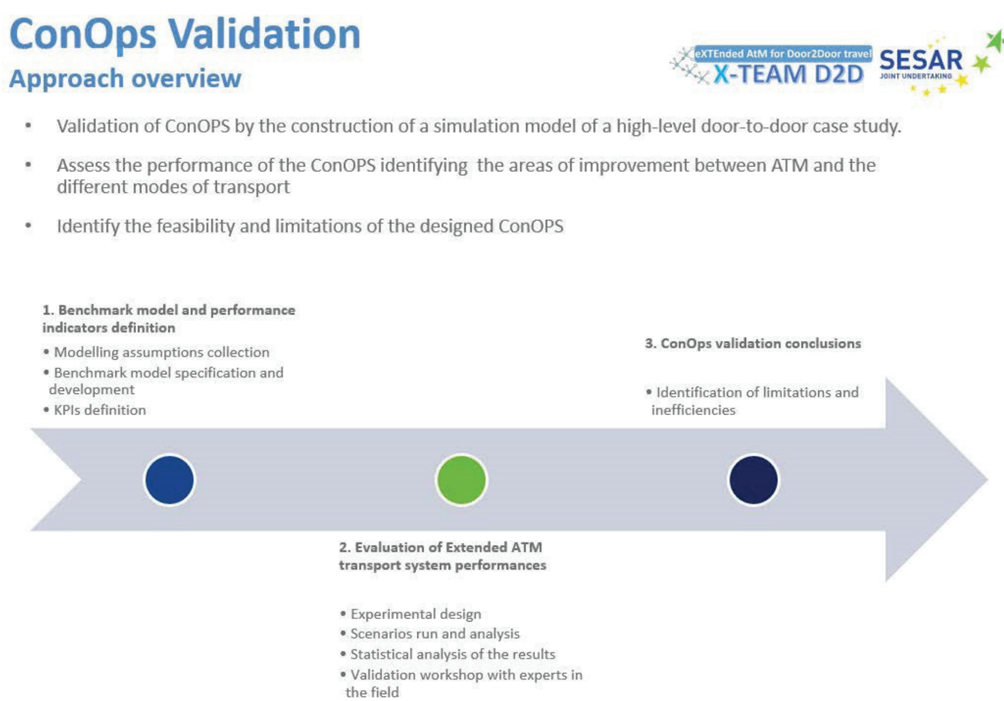

Figure 5. X-TEAM D2D approach to ConOps validation.

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.

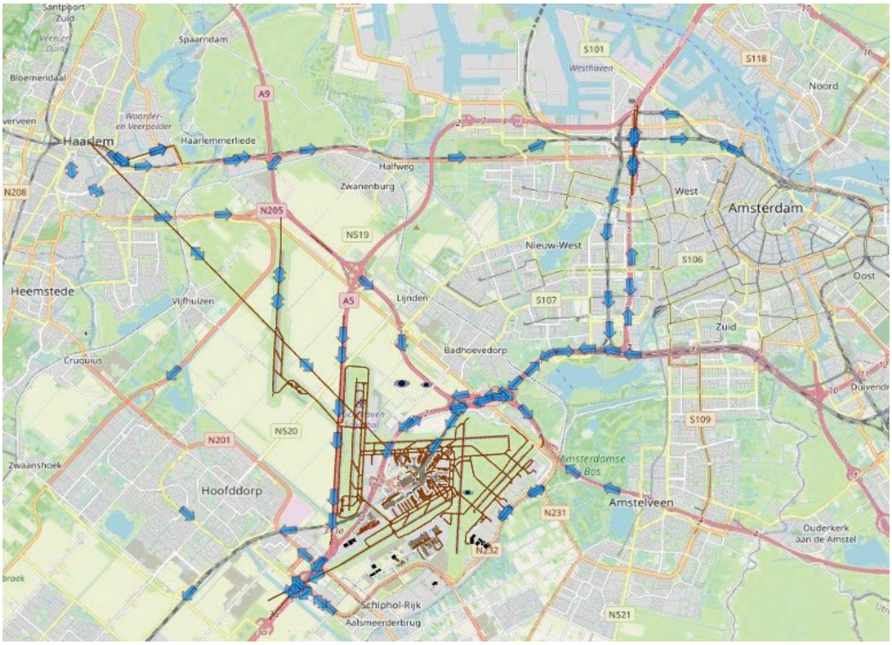

Figure 6. Door-to-airport part of the X-TEAM D2D simulation model [17].

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.

Author Contributions: Writing—original draft preparation, V.D.V.; writing—review and editing, V.D.V.; scenarios and barrier studies, B.D., M.M. and A.M.; integration of ATM in intermodal transport infrastructure studies, V.D.V., R.V.M., G.C., F.N. and L.B.; integration of ATM in intermodal service to passenger studies, P.A.M., G.D., R.R. and S.P.; validation and simulation, M.M.M., M.B. and A.e.M. All authors have read and agreed to the published version of the manuscript.

Funding: X-TEAM D2D project has received funding from the SESAR Joint Undertaking (JU) under grant agreement No 891061.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Requests for information about data may be sent to the authors at the indicated emails.

Conflicts of Interest: The authors declare no conflict of interest.

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Article

Passenger Dimensions in Sustainable Multimodal Mobility Services

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Abstract: Seamless integration of air segment in the overall multimodal mobility chain is a key challenge to provide more efficient and sustainable transport services. Technology advances offer a unique opportunity to build a new generation of transport services able to match the evolving expectations and needs of society as a whole. In this context, the passenger-centric approach represents a method to inform the design of future mobility services, supporting quality of life, security and services to citizens traveling across Europe. Relying on the concepts of inclusive design, context of use and task analysis, in this article, we present a comprehensive methodological framework for the analysis of passenger characteristics to elicit features and requirements for future multimodal mobility services, including air leg, that are relevant from the perspective of passengers. The proposed methodology was applied to a series of specific use cases envisaged for three time horizons, 2025, 2035 and 2050, in the context of a European research project. Then, passenger-focused key performance indicators and related metrics were derived to be included in a validation step, with the aim of assessing the extent of benefit for passengers that can be achieved in the forecasted scenarios. The results of the study demonstrate the relevance of human variability in the design of public services, as well as the feasibility of personalized performance assessment of mobility services.

Keywords: passenger-centric mobility; door-to-door journey; multimodal air transport; social sustainability; inclusive design

Citation: Duca, G.; Trincone, B.; Bagamanova, M.; Meincke, P.; Russo, R.; Sangermano, V. Passenger Dimensions in Sustainable Multimodal Mobility Services. *Sustainability* **2022**, *14*, 12254. https://doi.org/10.3390/su141912254

Academic Editor: Aoife Ahern

Received: 12 August 2022
Accepted: 22 September 2022
Published: 27 September 2022

1. Introduction

In the report "Our Common Future" published in 1987 by the World Commission on Environment and Development of the United Nations Environment Programme, sustainable development is defined as "development that ensures that the needs of this generation are met without compromising the ability of future generations to meet their own needs" [1]. According to this definition, the concept of sustainability is linked economic, social and environmental pillars. The social dimension is crucial for the sustainability of future transport [2] and has been one of the key aspects of the X-TEAM D2D (Extended ATM for Door-to-Door travel) project. X-TEAM D2D is a European research project in the context of seamless door-to-door mobility in urban and suburban, as well as regional, environments, including air travel. The concept of door-to-door multimodal journeys refers to the use of various modes of transport (air, rail, bus, road or maritime) by travellers to complete a single journey perceived as an all-in-one experience [3].

The X-TEAM D2D project has explored the scenario of the connection of a large metropolis with the surrounding area, up to the national level. Specific journey paths (use cases) are defined according to the transport and passenger service scenarios expected to be available in the coming decades, according to baseline (2025), intermediate (2035) and final

(2050) time horizons. The focus of this study is the concept of passenger-centric multimodal door-to-door journeys and its application in possible future travel paths as an approach to the social sustainability of future transport systems and services.

Multimodal infrastructure refers to the network of airports, seaports, roads, railways, public transport systems, and human-powered mobility options that are integrated and coordinated to form a transport system to move people or freight from one point to another [4,5].

A seamless multimodal experience might include, for instance, travelling on two or more forms of transport with a single ticket (e.g., rail and air). In general, the more effectively these modes support and interconnect with one another and the more seamless the intermodal connections (the movement of passengers or freight between modes of transport), the less congestion and the less stress on any individual component [6–8]. As air traffic is concentrated at hub airports, constraints arise, such as long walking distances and delays. Passengers must wait at hub airports for connecting flights, often for longer than necessary, as flight co-ordination is less efficient, and minimum connection time is long, especially at largest hubs. Furthermore, modern passengers request fast, efficient and, in many cases, environmentally friendly transport connections; the era of transport rivalry must become a thing of the past, and if mobility is to be safeguarded in the long term, the various modes of transport will have to work together [9].

What passengers demand depends on their specific needs. Meeting these needs will become an increasingly competitive endeavour [10]. Online information and electronic booking and payment systems integrating all means of transport should facilitate multimodal travel. Regardless of the sophistication of a system, it cannot achieve success if does not serve passengers. Acquiring knowledge of passenger feedback is the first step towards well-organized and satisfactory intermodal connection and interchange nodes with efficient baggage-handling logistics and integrated ticketing, which could serve as a foundation for socially sustainable transport multimodality [11]. Passengers demand that companies along the door-to-door (D2D) air travel value chain, in terms of overall experience quality [12], to adopt measures aimed at the overall personalization and digitalization of journeys, as well as establish partnerships with other providers and tech companies. Table 1 shows the key user expectations [13] and some associated key aspects of the travel experience.

Barriers related to the needs and expectations of future multimodal passengers are mainly associated possible inequalities and gaps that might arise or increase in future scenarios as a consequence of socioeconomic trends, such as gentrification or polarization of social classes [14–16]. In principle, any new product or service resulting from technological or business innovation aims to match user needs and satisfy (and possibly exceed) user expectations. In this context, eliciting passenger characteristics and needs and identifying associated meaningful key performance indicators (KPIs) are key steps with respect to the understanding of current barriers, the ideation of future mobility services, the conceptualization of new services that overcome identified barriers, the assessment of future services, the understanding of changes in environmental sustainability and user experience of newly designed services [3].

Table 1. Aspects of passenger expectations with respect to mobility services.

Passenger Expectation	Key Aspects
Convenience	• Clear indication of costs • Services offered for the selected transport path, taking into account extra comfort demands
Ease	• Accessibility of information and data, facilitating electronic data exchange across borders and timely updating of information • Simplicity in both booking and costs • Clearly identification of connections • Possibility of integrated tickets • Simplicity in understanding how to purchase tickets
Frequent and fast	• Integrated information about the whole journey, awareness about real-time data, e.g., information about strikes, disruptions and delays
Exhaustiveness	• Privacy and liability issues • High level of protection (rights, information, services, etc.) with respect to multimodal products compared to mode-specific services (single contracts versus separate contracts for each mode) • Accessibility of information regarding temporary or permanent passenger impairments (specific needs) • Luggage security (both in terms of lost and stolen luggage and) • Accessibility of vehicles, streets and stations
Reliability	• Care and assistance in the event of travel disruption • Rerouting so that passengers can arrive at their destination as soon as possible • Reimbursement and/or compensation when relevant

2. Materials and Methods

2.1. Theoretical Framework

To elicit, harmonise and appropriately consider the variety of passenger needs resulting from demographic change and new technologies and transport services available in the 2025, 2035 and 2050 time horizons as well as to accommodate the increasing awareness of multimodal passenger rights and expected service quality, a series of applicable concepts and approaches were surveyed. These concepts were selected to ensure:

- Consideration of EU principles of equality and human rights with respect to access to public services [17];
- Creation of a set of passenger-related data to be combined with air traffic management (ATM) and other transport data for an affordable, accessible and seamless multimodal travel experience; and
- Meaningful profiling of multimodal and air transport passengers.

In this view, the key reference concept is inclusive design. inclusive design related to optimization of the use of a system or a service for a user with specific needs (usually, this user is an extreme user, meaning that they have particular needs). By focusing on extreme users, many other users with similar or lesser needs will benefit from the intended system or service so that a wider diversity of people can make easy use of it [18]. Therefore, inclusive design results in a system and/or a service that is accessible to and usable by as many people as reasonably possible without the need for adaptation or specialised design for specific user categories [19]. The inclusive design framework includes the concept of transgenerational design, which is specifically aimed at making systems and services compatible with physical and sensory impairments associated with human aging and that limit major activities of daily living [20]. The inclusive design approach considers the full range of human diversity with respect to ability, language, culture, gender, age and other forms of human difference [21], supporting the elicitation of a wide range of human characteristics to cover the permanent and temporary needs of all passengers [22,23].

Table 2 below provides some examples of how travel services can accommodate the needs of many passengers by addressing the specific necessities of a traveller with special needs, according to the inclusive design approach.

Table 2. Examples of passenger typology benefiting from inclusive solutions.

Specific Disability	Technical/Organizational Solution	Other Passengers Benefiting from the Specific Solution
Deafness	Subtitled video instructions on aircraft safety procedures	Non-English-speaking passengers Elderly passengers with reduced auditory ability Passenger listening audio on personal devices
Arm/hand impairment	Luggage pickup at departure door and delivery at arrival door	Parent holding a baby

It is also clear that the ability to access and a door-to-door multimodal journey depends not only on personal characteristics but, sometimes to a greater extent, on the overall context in which passengers act and behave during their journey. According to this approach, eliciting passenger needs also requires that context and situations are properly considered; to support these aspects, we refer to the context of use concept and the task analysis technique. The concept of context of use was first introduced in the context of digital interface usability [22] and is extensively used to represent the combination of the goals, characteristics, tasks, objects and environment characterizing the situation in which users interact with a system or service [24,25]. The context of use perspective also considers the variety of real-world contexts and the three time horizon scenarios with respect to which mode of travel passengers must be enabled to access in order to appropriately address their needs. The third component of this approach to user needs analysis (and according to the use case definition) is the adoption of the task analysis technique to identify the main actions during the multimodal journey that the passengers must be able to carry out in the most efficient way. Task analysis is a well-established human factors technique [26] that has been used in the X-TEAM D2D project to break down the high-level "multimodal journey" task into a sequence of smaller and more contextualized tasks, allowing for identification of all the details of the context of use, from the environment (i.e., train station, moving bus, airport moving sidewalk, etc.) to the goal (changing a reservation, dropping off luggage, etc.), the passenger (age, impairments, scope of travel, language, etc.) and objects/equipment (smartphone, credit card, suitcase, stroller, etc.).

2.2. Passenger Characterization

Passengers deal with a number of variables when planning a door-to-door multimodal travel, as well as when rearranging travel plans in the case of disruption. The relevance and priority of each variable can differ according to the specific passenger profile. On the other hand, the passenger profile results from the combination of permanent personal characteristics (such as age, gender and permanent physical abilities) and contextual or temporary characteristics (such as the purpose of travel, the number of people travelling with the target passenger, knowledge of the sites and language of the destination, the availability of enabled credit cards, etc.). Each characteristic of a passenger profile contributes specific needs or expectations to be matched, requiring that mobility services as a whole provide specific tangible or intangible features in terms of functions supporting passenger tasks and goals. From the perspective of passenger experience, a set of high-level travel variables can be identified as relevant in terms of shaping the optimal travel pattern; each variable can be managed by the passengers through the functions or services available during the planning or execution of their D2D journey [27]. Each feature can satisfy a basic need of travellers (as is the case of slider for people with walking impairments), representing a mandatory function or service for passengers to succeed in their door-to-door journey or. From the perspective of inclusive design, this can be an additional element providing a more satisfying travel experience to passengers with varied profiles, as in the case of slider for passengers with large and heavy luggage [28]. Relying on the above conceptual references, we conducted a review of the needs of passengers according to their characteristics and journeys, taking into consideration the following multimodal travel variables:

- Travel time;
- Connections and number of modes;
- Accessibility and comfort of each travel segment;
- Cost and level and services provided;
- Personal security;
- Luggage security;
- Environmental impact;
- Ticketing;
- Early and real-time information provision;

Furthermore, we considered the following possible personal characteristics (i.e., human variables) of passenger:

- Visual impairments;
- Auditory impairments;
- Walking impairments;
- Women travelling alone;
- Families/groups with children;
- Business travellers;
- Leisure travellers;
- People travelling for personal reasons other than leisure;
- Non-native language speakers;
- Low digital trust/personal device accessibility; and
- Enabled credit card holders (or no cash availability).

The figures below provide an overview of the variables relevant to passengers; for each of these travel variables, we identified a series of transport service features enabling the management, or at least the partial control, by passengers (Figures 1 and 2). In a further step, we defined the relevance (crucial or optional) of each feature for the achievement of travel tasks according to specific passenger characteristics. Table 3 provides examples of key travel variables and the corresponding features of mobility services matching the identified needs.

Table 3. Examples of travel variables and needs according to passenger profiles with respect to the multimodal travel variable "connections and number of modes".

Feature Enabling the Management of the Variable	Mandatory for Passengers Who Are/Who Have	Appreciated by Passengers Who Are/Who Have
Making travel arrangements for a number of connections	Visual impairments Walking impairments Families/groups with children Business travellers Travelling for personal reasons other than leisure	Auditory impairments Leisure travellers Non-native language speakers
Selecting travel options according to the type of mode (i.e., no road journey, car, bike, kick scooter sharing services, etc.)	Visual impairments Auditory impairments Walking impairments	Women travelling alone Families/groups with children Leisure travellers Non-native language speakers

Table 3. *Cont.*

Feature Enabling the Management of the Variable	Mandatory for Passengers Who Are/Who Have	Appreciated by Passengers Who Are/Who Have
Arranging travel options according to length and walking time on pedestrian paths	Visual impairments Walking impairments Women travelling alone Business travellers Travelling for personal reasons other than leisure	Families/groups with children Leisure travellers
Arranging travel options according to the length of outside walks	Visual impairments Walking impairments Women travelling alone Business travellers Travelling for personal reasons other than leisure	Families/groups with children Leisure travellers
Arranging travel options according to the number of floor changes	Visual impairments Walking impairments	Families/groups with children
Arranging travel options according to the availability and position of elevators	Visual impairments Walking impairments	Families/groups with children
Arranging travel options according inclusive wayfinding infrastructure (audio and tactile for visually impaired passengers, written/graphics for auditory impaired passengers, etc.)	Visual impairments Auditory impairments Walking impairments	Women travelling alone Families/groups with children
Provision of detailed directions in the case of multiple entrance/exit points	Visual impairments Walking impairments Women travelling alone Business travellers Travelling for personal reasons other than leisure Non-native language speakers	Auditory impairments Families/groups with children Leisure travellers
Preview of waiting/entrance/exit points and routes (i.e., google street view), audio description	Walking impairments	Auditory impairments Women travelling alone Families/groups with children Business travellers Leisure travellers Travelling for personal reasons other than leisure Non-native language speakers

Passenger profiling is intended to provide the key information about passengers' expected behaviour (i.e., is voluntary or obliged choices among alternatives) that could determine the sequence of actions constituting the door-to-door travel to be executed by a given passenger in a specific time horizon. Passenger profiles contribute to the design of the workflow describing the steps of multimodal journeys, in addition to providing indicating the most plausible alternative workflow in the case of travel disturbances, for example, requesting passengers to switch to an alternative transport mode or timetable.

The X-TEAM D2D project defined 18 use cases with corresponding workflows based on two types of travellers with distinctive characteristics and occurrences in travel: business travellers (BT) and travellers visiting friends and relatives traveller (VFT); the latter comprises a group of 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). For each traveller, a use case scenario including all steps, from planning to post-travel management, were considered with respect to each of the time horizons (2025, 2035 and 2050). Each of these time horizons is assumed to be associated with different technological states and different levels of integration of transportation systems. In addition, disruptions and delays in the travel process were considered so that for each time horizon and passenger type, the journey workflow was developed according to nominal conditions, i.e., a disruption communicated before the start of the journey and with a disruption occurring during the journey. Disruptions information was assumed to be available to the traveller at two time points: information available at least five hours before departure and information becoming available during the journey. Disruptions could be the result of technical failures or error made by bus/train drivers or infrastructure operators (internal reasons), accidents concerning interactions between modes of transport (e.g., a train hitting a pedestrian at a rail crossing), adverse weather conditions, blackouts or terrorist attacks. The probability of an internal reason for a delay and accidents is comparable and much more likely than adverse weather conditions, blackouts and terrorist attacks. The time necessary for a full recovery after a disruption depends on the circumstances.

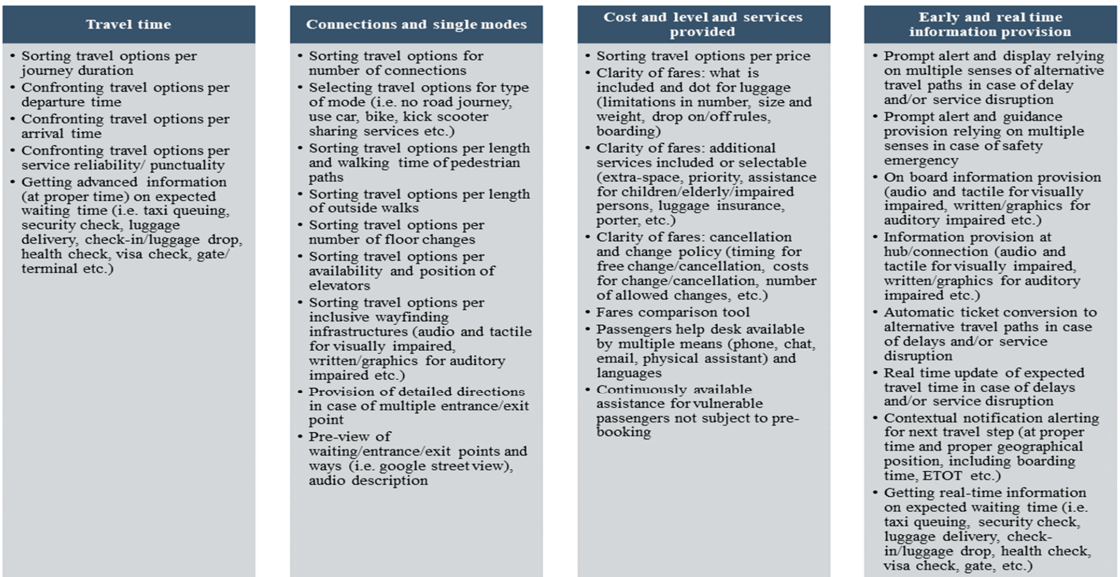

Figure 1. Features of transport services relevant to passengers with respect to travel time, connections, cost, level of services provided in advance and real-time information provision.

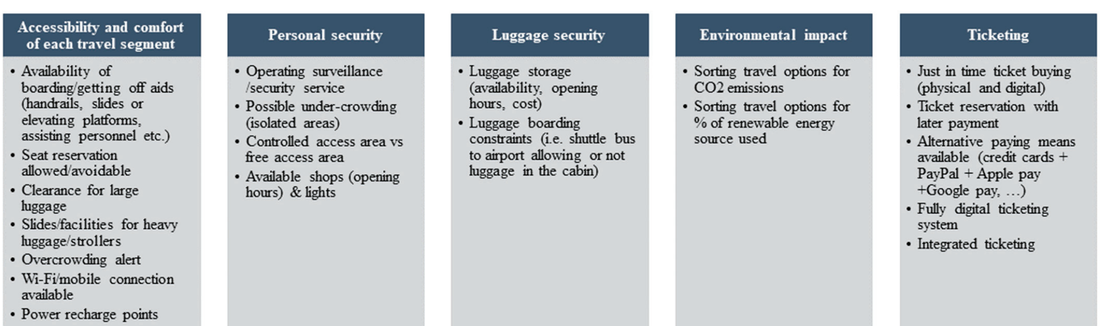

Figure 2. Features of transport services relevant to passengers with respect to accessibility and comfort of each travel segment, personal security, luggage security, environmental impact and ticketing systems.

In order to define the most plausible workflows in the 18 investigated use cases, the key characteristics and subsequently expected behaviour for each passenger type was defined, as depicted in Tables 4–6.

Table 4. Key passenger profile points for the 2025 scenario.

Passenger Type	Characteristics	Expected Behaviour
Business Traveller (BT)	Travels alone (mainly) Has time constraints/target times Has budget limits, although these generally depend on the business goal of the trip and the role of the traveller in the company Short stay and cabin luggage Might need to work during the travel time Frequent flyer/traveller Adult (18–70 years), generally in good health condition (no physical or sensorial impairments) May or may not be allowed to arrange/rearrange travel plans, depending on internal procedures	Can easily and quickly adapt to travel plan changes Habitually uses on-demand/personal transport means (e.g., taxi or car rental) Spends little time planning the trip; the trip is not arranged well in advance Chooses the fastest multimodal journey combination Chooses the most comfortable mode of travel (i.e., with reservation) May rely on travel assistance services (e.g., secretary services or traveller club services)
Other traveller (OT)	Travels in small or large groups (mainly) With the exception of specific travel reasons (a ceremony, family issues, etc.), has relatively low time constraints Has budget limits May travel with large/heavy luggage or other items, such as sport equipment, walking aids, stroller, etc. May require assistance (e.g., children, elderly and disabled people) May or may not be a frequent flyer/traveller Can of any age, from baby/children to very elderly Can have any kind of physical or sensorial impairment Is free to arrange/rearrange travel according to their preferences May be constrained in terms of payment method (i.e., unavailable credit card, unavailable cash, etc.) May encounter language/communication barriers	Carefully plans travel in advance (mostly) Could be unable or unwilling to use some modes of transport (i.e., due to accessibility barriers, costs, etc.) Could use shared modes of transport with personal accounts (car/bike sharing, Uber, etc.) May prefer cheapest travel options (disregarding comfort or travel time)

Table 5. Key passenger profile points for the 2035 scenario.

Passenger Type	Characteristics	Expected Behaviour
Business Traveller (BT)	Travels alone (mainly) Expects a very high standard of comfort Expects very short travel time Has few budget limits Travels for short stay, with small luggage Is a frequent flyer/traveller Is an adult (18–70 years), generally in good health condition (minor physical or sensorial impairments) Relies on dedicated business services for travel arrangement (no reservation or payment method constraints) Has full flexibility for change of travel plans	Spends little time in planning the trip; the trip is not arranged well in advance Uses personalized/on-demand travel services, even if at higher cost Chooses the fastest multimodal journey combination Chooses the most comfortable mode of travel (i.e., with reservation), with priority for the easiest connection Might choose mode of travel to show status, according to their position in the organization (will consider some modes of travel more representative than others, i.e., for urban air mobility) Might choose mode of travel to reinforce sustainability policies of his/her company
Other traveller (OT)	Travels in small or large groups (mainly) With the exception of specific travel reasons (a ceremony, family issues, etc.), has relatively low time constraints May travel with large/heavy luggage or other items, such as sport equipment, walking aids, stroller, etc. Has budget limits Does not have constraints with respect to reservation or payment methods May require assistance (e.g., children, elderly or disabled people) Can be of any age, from baby/children to very elderly Can have any kind of physical or sensorial impairment Is free to arrange/rearrange travel according to their preferences Is sensitive to the environmental footprint of his/her journey Has no communication limitations, thanks to technology support	Plans travel carefully and in advance (mostly) Could be unable or unwilling to use some modes of transport (i.e., due to accessibility barriers, costs, etc.) Could be willing to pay environmental footprint compensation costs Could use shared modes of transport with personal accounts (car/bike sharing, Uber, etc.)

Table 6. Key passenger profile points for the 2050 scenario.

Passenger Type	Characteristics	Expected Behaviour
Business Traveller (BT)	Travels alone (mainly) Expects very high standard of comfort Expect very short travel time Has few budget limits Might travel for long stays (as short travel 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 arrangement (no reservation or payment method constraints) Has full flexibility for travel plans changes Must comply with environmental performance targets set by his/her company	Uses personalized/on-demand travel services Can easily and quickly adapt to changes in travel plans Chooses the fastest multimodal journey combination Chooses the most comfortable mode of travel /i.e., with reservation), with priority for the easiest connection If needed, will bear extra costs to pay carbon compensation or any environmental compensation amount to comply with sustainability targets of their company Might rely on travel assistance services (e.g., secretary services or traveller club services)
Other traveller (OT)	Travels in small or large groups (mainly) With the exception of 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/strollers) Has budget limits Has no constraints for reservation or payment methods Frequently travels with short stays/medium distance Might need assistance (children, elderly and disabled people) Can be of any age, from baby/children to very elderly Can have any kind of physical or sensorial impairment Is free to arrange/rearrange travel according to their preferences Is sensitive to the environmental footprint of his/her journey Has no communication limitations (due to good education and/or technology support)	The trip could be arranged with little notice Chooses the lowest environmental footprint travel option within the budget limits Uses luggage transfer services for "hands-free" travel Could use shared modes of transport with personal accounts (car/bike sharing, Uber, etc.) Will use any mode of transport (as any mode will be fully accessible)

2.3. Passenger-Centred Requirements for Multimodal D2D Journey

When planning and undertaking a trip, passengers have different needs and priorities to fulfil. These needs and proprieties are presumed to affect the tasks and decisions, as well as expectations about the quality of the transport services, and can be assigned to three stages of a journey, roughly in conformity with following three steps: pre-trip, wayside and on-board [29]; in some cases, a post-trip step is included. To execute the door-to-door journey, passengers interact with a series of information, as well as tangible and intangible infrastructure, which comprise the mobility service as a whole. This occurs in one or more travel steps, from planning to completion; as consequence, passenger-centred requirements for multimodal D2D journeys can be elicited with reference to both the journey steps and the components of the mobility service. Within this framework, the service design perspective supports [30] the passenger-centric approach sought by the X-TEAM D2D project, with the definition of requirements aimed at fitting the variety of characteristics and needs of any type of passenger. In order to fully match this scope, the definition of passenger-centred requirements of multimodal transport services was driven by the following principles:

- Inclusion of physical, social and cognitive differences to ensure equal access to D2D mobility services;
- Autonomous and independent living to safeguard human dignity and personal freedom with respect to the use of D2D mobility services; and
- Transparency of the mobility services provided to protect passenger rights and awareness.
- The Tables 7–9 below provide a list of high-level requirements of multimodal door-to-door journeys elicited according the abovementioned methodology. The requirements are defined with reference to the mobility service components, namely:

- Requirements of applications and devices enabling the use of the mobility service (organizational part of the service);
- Requirements of wayside spaces (hubs, nodes and built infrastructure); and
- Vehicle requirements.

Table 7. Requirements of applications and devices enabling the use of the mobility services.

Requirement	Relevant Journey Step			
	Pre-Trip	Wayside	On-Board	Post-Trip
Access to mobility services should rely on the lowest technological standards (to avoid any digital divide)	⊙	⊙	⊙	⊙
Personal data required to access and manage travel services should be minimized	⊙	⊙	⊙	⊙
Multiple alternative payment/refund methods should be allowed, including more than one currency; cash payments should always be possible [31]	⊙	⊙	⊙	⊙
Search tasks should allow results to be sorted by multiple criteria	⊙	⊙	⊙	
Information should be provided with symbols and graphics supporting the text	⊙	⊙	⊙	⊙
Information should be accessible on personalized auxiliary tools (i.e., text-to-speech systems), and information should be accessible by more than one medium (i.e., reading as an alternative to listening)		⊙	⊙	⊙
Information should be provided with relevance to the context (i.e., appropriate time and place for the requested action)		⊙	⊙	⊙
When applicable, information should be offered with multiple level of detail	⊙	⊙	⊙	
Information constituting the contractual basis of travel services should be accessible and retrievable at any time	⊙	⊙	⊙	⊙
Integrated ticketing of all travel legs should be available				⊙
Seat reservation should be available for travel legs longer than 30 min	⊙	⊙		
Automatic changes of journey plans to manage travel disruptions should be subject to confirmation; further personalization of proposed change should be allowed without extra cost (for equivalent services); information on extra costs should be clearly provided and subject to confirmation		⊙	⊙	
Information on available primary and secondary services should be available from the ticketing/booking stage	⊙			
If autonomous boarding and disembarking is not possible, assistance should be available without prior request or booking		⊙	⊙	

Table 8. Requirements of hubs, nodes and built infrastructure.

Requirement	Relevant Journey Step		
	Pre-Trip	Wayside	On-Board
Access, egress and turning points should be easily to independently locate according to the physical, cognitive or sensorial abilities of passengers; if not fully accessible, assistance service should be available without pre-booking.	⚬	⚬	
Long walking distances should be supported by moving aids (i.e., moving walkways, shuttles, etc.)		⚬	
Escalators, elevators and means to overcome differences in floor height should be available and included in the main walking path	⚬	⚬	
Walking times should be indicated, with multiple figures referring to a variety of passenger characteristics	⚬	⚬	
Outside walking paths should protect passengers from weather conditions (e.g., rain, cold, heat and wind)		⚬	
Racks and stands for personal mobility devices should be directly connected to access/egress points	⚬	⚬	
Racks, stands and layaway of shared mobility devices should be directly connected to access/egress points	⚬	⚬	
Healthy and comfortable indoor environmental conditions should be assured (i.e., internal air quality (IAQ), lighting and noise)		⚬	
Resting/meeting points should be available along long walking paths		⚬	
Primary services (i.e., electrical outlets, telecommunication network coverage, toilets, etc.) should be available in all areas of hub buildings		⚬	
If secondary services (i.e., passenger assistance, security points, ATMs, pharmacies, etc.) are not available in hub buildings, information on the nearest service location or access should be provided		⚬	

Multimodal travel variables, passenger characteristics and requirements for passenger-centred multimodal door-to-door journeys were reviewed in consultation with the Passengers Advisory Group of the X-TEAM D2D project, consisting of representatives of POLIS Cities and Regions for Transport Innovation (to verify the mobility the integration perspective), the EPF European Passengers Federation (to verify the evolution over time and access to services perspective), C.E.R.P.A. Italia Onlus—European Center for Research and Promotion of Accessibility (to verify the inclusion perspective) and Legambiente Italia (to verify behavioural changes and attitudes towards environmental sustainability).

Table 9. Vehicles requirements.

Requirement	Relevant Journey Step		
	Pre-Trip	Wayside	On-Board
Autonomous/independent boarding and disembarking should be ensured; if not fully accessible, assistance service should be available without pre-booking.		⚬	⚬
Primary services (i.e., Wi-Fi and toilets) should be available in the case of travel legs longer than 30 min			⚬
Seat layout should allow for passenger privacy			⚬
Seats layout and clearance should allow for accommodation of all personal belongings			⚬
Healthy and comfortable indoor environmental conditions should be assured (i.e., internal air quality (IAQ), lighting and noise)			⚬
Personalised levels of environmental conditions should be possible in the case of travel legs longer than 1 h (i.e., internal air quality (IAQ), lighting and noise)			⚬

3. Results

3.1. Application of Passenger-Centric Approach in the X-TEAM D2D Project

The X-TEAM D2D project included validation activities with the aim of evaluating the impact of envisaged future multimodal mobility services on the passenger journey; such validation was implemented in a general-purpose discrete event simulation software. Three groups of elements were implemented in the model. The first group, dynamic entities, represents passengers and vehicles transporting passengers from their point of origin to the airport. The second group, static elements, represents transport stations used by passengers to board/disembark transport vehicles. These stations serve as the entry, transfer and exit points, 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 edges connected into a network that vehicles and passengers use to move through the space between transport stations. Within the framework, the arrival of passengers and most modes of transportation are generated stochastically based on the project assumptions. Some modes of transport (such as buses and trains) are generated on a schedule, as observed in real-life operations.

In order to assess the efficiency and quality of the system elements, several key performance indicators (KPIs) were defined for analysis and comparison of different time horizons and different multimodal network setups. By nature, the aim of a system of performance indicators is to evaluate the success of an organization or an activity with respect to a desired output in a given context [32]. With respect to D2D multimodal journey passengers, key performances indicators should represent the relevance (key) of one or more specific aspects of the D2D mobility service to a specific type of passenger with respect to his/her expectations and needs (Performance) that can be quantitatively measured (indicator). In addition, within the X-TEAM D2D framework, KPIs should be carefully selected to either be applicable at the abstraction level set for the simulation or to provide useful information [33]. This is particularly relevant for the passenger-centric and step-wise approach of the X-TEAM D2D project because it is acknowledged that performance measurement and monitoring significantly impact the development, implementation and management of existing transport plans and programmes, largely contributing to the identification and assessment of successful alternative scenarios. Furthermore, consideration of specific passenger-related KPIs paves the way for the comparison, from 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 [34]. When defining passenger-related KPIs, the following aspects should be taken into account [34]:

- 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 and social inclusion;
- Available resources and tools for measurements; this means that performance should be measurable with available tools and resources, costs should be reasonable with respect to budget, accuracy levels should be comparable with respect to requirements and data should be retrievable through field measurement;
- Possibility to compare future alternative scenarios and to use existing forecasting tools to define such scenarios;
- Understandability by policy makers, professionals and the general public;
- Direct measures of the issue of concern or at least maximum relevance or meaningfulness;
- The combination of modes, legs and steps of the multimodal journey; and
- Performance measures should allow for control and improvement of the measured characteristics, i.e., they should provide decision makers with relevant information for their decision-making processes.

3.2. Passenger-Focused KPIs and Metrics

Combining the passenger-centred perspective and the passenger-centred requirements defined so far, it is possible to derive passenger-focused KPIs, which should address the performance areas summarized in Table 10 [33,35].

Table 10. Relevance of KPIs according to passenger profiles.

KPI	Relevance Per Passenger Profile	Direction	Data Availability
Total travel time	BT ○○○ VFRT ○	Less time is preferred	Usually available in standardized form
Waiting time at interconnections	BT ○○○ VFRT ○○	Less time is preferred	Usually available in standardized form
Frequency (probability) of delays resulting from breakdowns/maintenance, etc.	BT ○○○ VFRT ○○	Lower probability is preferred	Possibly available but not standardized
Accessibility of wayside infrastructure	BT ○○ VFRT ○○○	Fewer barriers are preferred	Requires specific data collection
Luggage security	BT ○ VFRT ○○○	Lower probability of loss and theft is preferred	Requires specific data collection
Ticketing user-friendliness	BT ○ VFRT ○○○	Less time spent for ticketing is preferred	Requires specific data collection
Response time to service interruptions	BT ○○○ VFRT ○○	Shorter recovery time is preferred	Usually available in standardized form
Travel time reduction	BT ○○ VFRT ○○	Reduction is preferred	Usually available in standardized form
Number of modes included in a single ticket	BT ○ VFRT ○○○	More is preferred	Usually available in standardized form
Number and modes used	BT ○○○ VFRT ○○○	Less is preferred (or more available alternatives)	Possibly available but not standardized
Total cost of travel	BT ○○ VFRT ○○○	Lower cost is preferred	Usually available in standardized form

Different passengers have different needs and expectations, resulting in multimodal transport systems performing differently depending on the specific passenger type using the service (passenger perspective rather than operator perspective). Given the need to represent passenger variability through characteristics that can be measured compatibly with the available metrics adopted for defined KPIs and considering that time is a recurring metric, an example of a human variable that can be introduced to represent human variability in such validation exercises is walking speed. Walking speed varies according to age, physical and sensorial ability, gender, number of group members and many other variables. Table 11 lists walking speed according to passenger characteristics [36].

Table 11. Walking speed according to passenger category.

Passenger Characteristic	Walking Speed (m/s)
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 $\geq$ 65	Slowest (15th percentile): 0.92 m/s Fastest (85th percentile): 1.44 m/s
People with impairments (including wheelchair users, visually impaired persons and persons on crutches)	Slowest (15th percentile): 0.86 m/s Fastest (85th percentile): 1.49 m/s

In a further step, a passenger population sample was built according to demographic and other changes foreseen in each of the three scenarios (i.e., more impaired people travelling in 2035, more older business travellers in 2050 [37]), which are listed in Table 12.

Table 12. Passenger composition.

Category	2025	2035	2050
% of BT passengers > 65	5.8% [38]	7% (assuming that until 2035, retirement ages will increase to varying extents among EU countries)	9% [39]
% of VFR passengers with impairments [40]	6%	8%	10%
% of VFR passengers > 65 (assuming that older and retired people travel more than younger people)	19%	25%	32%
% of VFR passengers, including children	10% (NB: this is the percentage of 0–9 year-old EU population) [41]	9% (assuming that negative demographic trends will stop after EU governments change their policies in the future)	12% (assuming that new positive demographic policies and reinforced migration/integration flows will occur in the timeframe of 2030–2040 and due to increasing migration pressures)

3.3. Simulation Results Related to Passenger KPIs

The X-TEAM D2D simulation results provide insight into differences in gains over the three time horizons for the considered passenger profiles, supporting the understanding of social sustainability aspects in future multimodal air travel services [42]. In terms of the efficiency of multimodal connections, represented in this case by waiting time, business travellers will achieve the greatest improvement if they use on-demand operating transport, such as urban air mobility or new micromobility services to cope with disruptions in the 2035 scenario and especially in the 2050, when waiting time is significantly reduced or close to zero. As passengers travelling to visit relatives and friends are more dependent on mass forms of public transport, the greatest benefit is expected to be experienced starting from 2035, when they can access affordable on-demand transport services, significantly reducing wait times. Given the purpose of the simulation, data on transport means in the 2025 time horizon were been derived from current operating services in cities considered for the USE CASES, whereas data on transport means in the 2035 and 2050 scenarios were assumed based on transport forecasts studies.

The most advantaged traveller profile in terms of travelled distance is the VFR, as this group can benefit from 5% shorter travel distance in the 2050 scenario, regardless the occurrence of disruptions. The VFR group will also benefit from a 20% reduction in travel time in the 2050 scenario compared to 2025; moreover, disruptions will not affect travel distance in the 2050 scenario for such passengers.

Both passenger profiles will experience a progressive improvement in travel speed, up to 21% in the 2050 scenario; in 2035, business passengers will experience a larger reduction in travel speed in case of disruptions, whereas in 2050, travel speed for both passenger profile should not be affected by disruptions relative to regular journeys.

4. Discussion

Sociocultural trends show an increasing consideration of the relevance of passenger diversity and social inclusion; therefore, we foresee that in the near future, passengers belonging to vulnerable categories will expect full and equal access to all transport services. As a consequence, digital (i.e., travel management mobile applications) and physical travel infrastructure (i.e., buildings, urban areas, vehicles, etc.) will have to adapt to a broad variety of needs and expectations, as well as in response to trends in recommendations and directives at the EU level. Although real-time data are expected to progressively integrate and autonomously manage travel disruptions at a wide systemic level, it is very likely that extreme weather events will increase in the 21st century in many areas of the globe, impacting normal activity affected areas; in such cases, passengers will probably be informed of the expected disruption, but it may be difficult to complete the travel experience for vulnerable categories if the mobility services are not able to meet the variety of user needs. In this study, we proposed a methodological framework to understand passenger-related variables to be taken into account in the design of future multimodal mobility services so that all European citizen will have the right and opportunity to access a fundamental services. When planning and making a journey, passengers have different needs and priorities to meet; in this study, we discussed how the relevance and priority of each variable may differ depending on the specific passenger profile, also assuming that these needs and characteristics affect travel tasks and decisions, as well as expectations with respect to the quality of transport services. To this end, 18 use cases for future mobility services were assessed in a discrete event simulation context, in which some passenger variables were modelled and assessed with specific passenger-centric metrics in order to estimate the quality of future mobility services under an inclusive approach.

The estimation of social impact, especially in terms of inclusion and equality, is a key aspect of urban development programmes, although such programmes often only focus on consultation activities and qualitative measurement. The proposed assessment framework was developed for the estimation of the passenger centeredness of a specific type of future mobility services, although it can be replicated in a variety of cities and for several settings and combinations of multimodal transport. It may be useful to exploit more quantitative methodologies to develop projects in the field of multimodal urban mobility for passengers; therefore, the research application of the presented framework in the X-TEAM D2D project could be a starting point for new mobility projects, with the aim of developing impact foresight in a more concrete and meaningful way from the citizen's point of view. This will foster awareness of policy makers involved unban and mobility planning to implement more socially sustainable "Sustainable Urban Mobility Plans". The results of this study demonstrate the relevance of human variability in the design of public services, as well as the possibility of developing a system for personalized assessment of performance to support quality of life, security and services to citizens traveling across Europe considering multiple modes of transport, including air transport.

Author Contributions: Conceptualization, G.D.; Data curation, B.T.; Investigation, G.D.; Validation, M.B. and P.M.; Visualization, R.R. and V.S.; Writing—original draft, G.D. All authors have read and agreed to the published version of the manuscript.

Funding: This paper is based on research results of the X-TEAM D2D project. The X-TEAM D2D project received funding from the SESAR Joint Undertaking (grant no. 891061) under the European Union's Horizon 2020 research and innovation programme.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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Exploring the Efficiency of Future Multimodal Networks: A Door-to-Door Case in Europe

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Citation: 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. https://doi.org/10.3390/su142013621

Academic Editor: Lynnette Dray

Received: 2 August 2022
Accepted: 18 October 2022
Published: 20 October 2022

Abstract: It is expected that future transportation technologies will positively impact how passengers travel to their destinations. Europe aims to integrate air transport into the overall multimodal transport network to provide better service to passengers, while reducing travel time and making the network more resilient to disruptions. This study presents an approach that investigates these aspects by developing a simulation platform consisting of different models, allowing us to simulate the complete door-to-door trajectory of passengers. To address the future potential, we devised scenarios considering three time horizons: 2025, 2035, and 2050. The experimental design allowed us to identify potential obstacles for future travel, the impact on the system's resilience, and how the integration of novel technology affects proxy indicators of the level of service, such as travel time or speed. In this paper, we present for the first time an innovative methodology that enables the modelling and simulation of door-to-door travel to investigate the future performance of the transport network. We apply this methodology to the case of a travel trajectory from Germany to Amsterdam considering a regional and a hub airport; it was built considering current information and informed assumptions for future horizons. Results indicate that, with the new technology, the system becomes more resilient and generally performs better, as the mean speed and travel time are improved. Furthermore, they also indicate that the performance could be further improved considering other elements such as algorithmic governance.

Keywords: air transport; multimodal transport; passenger service; door-to-door transport; simulation; sustainable infrastructure; sustainable transportation

1. Introduction

According to the United Nations [1], by 2100, the world population is expected to reach approximately 10 billion people, and by 2050, more than 68% of the worldwide population will live in urban areas. To serve future mobility needs, physical infrastructure, transport systems, traffic management, operational processes, and information systems will be seamlessly integrated [2]. Furthermore, to efficiently move passengers between different means of transport, various systems that support passenger transfer between various modes of transport, such as park-and-ride [3] and shared mobility systems [4], among others, should work efficiently and be integrated with other travel support systems.

To explore how such integration and emerging transport technologies influence passengers' journeys, this work presents a study on how future multimodal transportation networks will impact passenger travel. The work is based on the concept of operations developed in the X-TEAM D2D project [5–8], where the authors were focused on modelling the concept of operations for the multimodal network.

The article continues as follows: Section 2 presents the important and related work. In Section 3, we summarise the concept of the multimodal network evolution towards

2050. In Section 4, we present the methodology developed for this study. Section 5 presents the characteristics of the passengers considered in the study. The experimental design and results are presented and described in Sections 6 and 7, correspondingly, and then conclusions, limitations, and future work are presented in Section 8.

2. Related Work

According to the European Commission [9], "multimodal transport" describes the use of various modes (or means) of transport during the same journey. This concept concerns both freight and passenger transport. It is expected that multimodal passenger transport benefits from the strengths of different modes that, combined, can provide people with more efficient transport solutions. When fully implemented, the multimodal transportation network should decrease road congestion and climate impact, making the whole sector safer and more cost-efficient. Ultimately, multimodality is expected to help creating a sustainable, integrated transport system [9]. Besides contributing to the sustainable development goals, multimodal transportation has been proven to contribute significantly to the economic development of urban territories [10–12].

Regarding door-to-door (D2D) travel, it is frequently studied from different points of view. Researchers have explored different angles of D2D travel. Some focused on the purpose of the trip [13], while others focused on population density, regional accessibility, the walkability index, and network density, among other aspects [14]. Other works focused on the service quality of transport systems. Some studies explored the usability of mobile services to improve the passenger experience, promote sustainable travel choices [15], understand travel behaviour [16], and measure users' satisfaction [17]. These works indicated that mobile communication could play a crucial role in integrating different services into one, offering multimodal transport opportunities to passengers. This is possible thanks to the ability of 5G and future expected 6G communication to support much faster data transfers related to multiple users compared to current mobile generation communications. Such an increase in data transfer capacity is a mandatory enabler for integrating different transportation means into an integrated multimodal system because such integration strongly depends upon the possibility of sharing passenger and infrastructure data from different transportation means. In addition, the indicated studies emphasised that mobile devices are the most eligible means to collect passengers' preferences data and allow users to communicate their preferences and perform their selections actively.

In the scope of D2D travel in one urban area, passenger satisfaction in railways [18–20], taxis [21], buses, and other forms of urban public transport [22–29] were extensively studied and discussed. A few studies explored connections between different urban areas in the form of transport combinations [30], high-speed trains [31], air travel [32,33], and air taxis [34]. Nonetheless, they do not always consider international travel with a door-to-door focus. In addition, none of the existing studies was also able to consider the integration of future available transportation means, such as Urban Air Mobility (UAM), inherently resulting in limited scope with respect to the consideration of such a possibility among the possible multimodality choices, which will become real in the next few decades.

European countries envision connecting different parts of the continent through a sustainable multimodal transport system that seamlessly joins all modes of travel, including air travel [35,36]. Such a multimodal travel network requires efficient and convenient planning and governance services. Based on EU regulation 2010/40/EU, the development of such a system evolves gradually and already includes several studies of potential IT architectures and service concepts to enable connectivity [37–42].

The organisational aspect of the multimodal network is also a relevant aspect to study. In line with the EU's Strategic Transport Research and Innovation Agenda [43], various studies explored the conceptual side of multimodal networks. Several projects, such as IMHOTEP and TRANSIT, proposed a concept of operations for collaborative decision making between airport operators and feeder transport stakeholders, including local transport authorities, traffic agencies, transport operators, and mobility service providers, providing travellers with a genuine door-to-door service [44–47]. Other efforts focused on performance measurements, mobility data analysis methods, and transport simulation tools for such a multimodal system [5,48,49]. The limitations of such studies are that, as others previously indicated, they do not consider transport integration in a multimodal way by including UAM as a crucial future actor. The resulting performance analysis, therefore, addresses multimodal networks lacking the possibility of efficiently exploiting the vertical domain in the urban environment.

The research done so far identified different issues present in the existing multimodal transport networks; some work revealed the speed ineffectiveness of public transport feeding European airports compared to private cars and taxis [50]. Another study revealed that by 2035 the passenger type, origin, available travel budget, and travel distance would also need to be considered when thinking about future D2D travel [51].

As discussed above, the topic of multimodal and D2D travelling has gained a lot of attention in the scientific community. Nevertheless, there are no studies on the performance of future transport systems considering the complete trajectory of the passengers (which could give insight into how passengers could benefit in the future from new transport technology). Furthermore, despite many research initiatives on multimodal transportation, supported by programs such as Horizon 2020, there are no studies on how such a multimodal transport network would affect passenger travel D2D from one country to another and whether 4 h D2D travel within Europe is feasible. This work aims to fill these gaps by presenting an innovative approach that enables the modelling and simulation of the complete D2D passenger journey, while incorporating novel technology as the time horizons change.

3. Conceptual Design of a Multimodal Network in 2025, 2035, and 2050

To explore how passenger journeys will change with the implementation of multimodal networks throughout Europe, we transferred the concept of operations (ConOps) of such a system into a simulation platform that allows us to estimate its performance. The evaluated ConOps was the one developed by the X-TEAM D2D project [5–8]. The details of the ConOps and its background analysis can be found in [52–56]. In particular, in these documents, the outcome of the project is reported, addressing: the definition of the future reference scenario for integrated multimodal transport and the related use cases [52], the incremental design of the ConOps for the integration of the different transport infrastructures [53,54], and the incremental design of the ConOps for the integration of the different transport services under a Mobility as a Service (MaaS) approach [55,56]. A summary describing the relevant elements is presented in the following sections.

3.1. System Outline in 2025

According to the review made by the X-TEAM project [52–56], in 2025, electric vertical take-off and landing aircraft (eVTOL) for Urban Air Mobility (UAM) operation will be implemented. On some routes, UAM will be implemented only for testing and demonstration. It will be managed with procedures and technologies available within the current Air Traffic Management (ATM) paradigm (either local or international). New mobility services (NMS), such as car sharing, ride hailing, bike sharing, e-scooters, and e-bikes, will gain user interest and obtain a significant share in the transport system. First light of Mobility as a Service (MaaS) and options such as single tickets with an optimised price considering different travel costs, integrated tickets, and their interoperability (flexible in case of disruptions) will be available in some areas.

Currently, there is still a lack of tools for exchanging and using data between the different transport modes in the immediate future. 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 the desired response in the event of a disruption. The existing ATM works with a well-established and proven safety management system but does not allow for rapid reactions and implementations. In contrast, U-Space is innovative and fast, but its security and robustness are not yet defined or validated.

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. By 2025, conformance monitoring will rely on currently available Air Traffic Management Communication, Navigation, and Surveillance (ATM CNS) capabilities and ATM and regulatory reporting mechanisms.

By 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 infrastructure. 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.

MaaS will only be available in some regional areas for a part of the transport modes. The extension 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, trams, and regional commuter trains) is still characterised by a 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 anything dealing with the methods and techniques used to prevent accidents. "Security" is concerned with protecting people and the system from criminal acts. Thus, a coherent and coordinated hazard and risk analysis will be established and agreed security requirements will be defined for the security-relevant functions of an urban-managed transport system.

3.2. System Outline in 2035

By this year, ATM will require new procedures and technologies not currently in use and will introduce Urban Air Traffic Management (UATM) Services to support UAM operations. These services will vary in type and maturity, from initial procedures and services to full implementation. Depending on the region, it will not be possible 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 ATM Data Services Providers (ADSP) support. 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 2025, passengers preparing for an intermodal journey in 2035 can use a U-Space service for their journey.

By 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).

3.3. System Outline in 2050

According to the X-TEAM project, for the 2050 time horizon, multimodal travel is characterised by a full range of services. The management systems will bring traffic management to a much higher level than the previous horizons.

By 2050, a highly automated ATM system with all-weather operation and a higher safety level will be available. It will cover service- and passenger-oriented management, relying on high connectivity, automation, and digitalisation.

Complete U-space 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 a robust 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 the flight segment.

4. Modelling Methodology

To translate the ConOps into a quantifiable design, we developed the case study considering two regions and their transport networks. As the project was looking into the far future, and we wanted to assess the complete D2D journey, we used a multi-layered simulation framework approach, since it was the only available technique that enabled us to consider the most relevant aspects of the travel, such as distances, speed, locations, capacity, network structure, and most importantly, the variability inherent to any dynamic system.

We modelled and simulated how passengers could travel from one town to another in different European countries. The selected regions are based on two types of airports:

- Regional airport—a non-hub airport without transfer traffic [57]. Hannover airport in Germany was taken as the base case. In this paper, this airport is referred to as APT-R.
- Hub airport—an airport that serves as a node for connecting different flight legs for several airlines [57]. Amsterdam Schiphol was taken as the base case. In this paper, this airport is referred to as APT-H.

The framework implemented the existing and future transport technologies following a multi-model approach. The existing transport network was created, verified, and validated based on existing transport information. The future transport modes were progressively added depending on the time horizon, considering relevant assumptions and the ConOps. As the characteristics of many of these future technologies are still unknown, expert-based assumptions had to be made regarding those technologies' characteristics and operational modes.

The conceptual model of the framework is presented in Figure 1. It consists of two models: the first reproduces the door-to-airport (D2A) leg of the passenger journey, and the second the airport-to-door (A2D) leg. Different available routes and operations were modelled in the following way. The transport networks were modelled as a combination of nodes and edges with different weights and characteristics, where the trajectory started at the passenger's origin and used the transport network (depicted in Figure 1 as nodes connected by edges) until they got to the APT node where the flight takes place. Then the same conceptual approach was followed for the final leg of the trajectory; the passenger started at the APT node, used the transport network—which has the available options of the time—and then got to the final node (final destination). The nodes are capacitated static elements in the network such as locations, airports, or stations, and the weighted edges represent the connections between the different locations. The connection between the two legs is made by another edge representing the flight connecting the two airports under study.

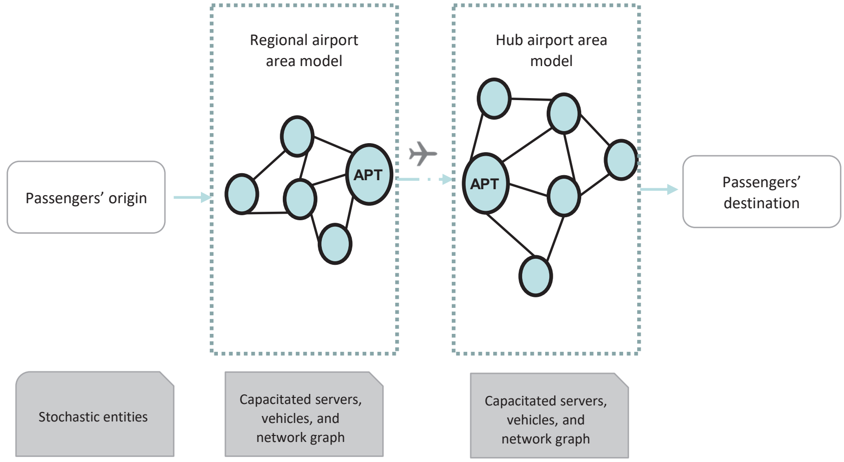

Figure 1. Schematic structure of the ConOps validation framework.

To make the models dynamic, we used a general-purpose simulator—SIMIO—that allowed us to include (apart from the nodes, edges, capacitated servers, and networks) dynamic entities such as vehicles and passengers, the variability inherent to the system, and a global clock that allowed us to evaluate the system's performance. The entities are injected into the model, and the performance is evaluated when they exit.

The sub-models were developed using a multi-layered approach [58], where we overlaid the model over a GIS layer from OpenStreetMap [59] so that the weighted edges consider the real distances between locations and the calculations made by the simulator could be as accurate as possible. Interactions of IT systems or management aspects of transport systems were not explicitly modelled in this framework.

A 2D view of the door-to-airport (D2A) model is shown in Figure 2. The presented maps correspond to the GIS layer used to determine the scales of transport connections for the models. The right image is the origin region (Brunswick), and the left represents the area where the regional airport is located (Hannover). These areas are located 60 km from each other. The road and railway networks connecting these two areas were modelled by an edge whose weight is the total distance between them.

A similar 2D view of the airport-to-door (A2D) model is shown in Figure 3. The PAX's destination city of Haarlem is located 10 km from Amsterdam Airport Schiphol (depicted on the map as APT-H).

The arrival of passengers and most transportation means were generated stochastically considering the assumptions present in the ConOps. Some elements available in the actual system (such as buses and trains) were generated on a schedule basis. For uncertain elements and performances of the future horizons, informed assumptions had to be made. For example, data sharing in 2025 will increase the system's transparency, especially in short-range airline connections, and good connections between the hub airport and the city by numerous transport modes (trains, bus connections, taxis) will exist.

There will be circumstances that might affect the expected results presented by the study, such as the regulatory framework for flying vehicles not being in place in the time horizon or the number of high-speed train connections being reduced in the future instead of increased. However, they could be part of another set of scenarios not considered in the current study. For clear information on the assumptions used, the reader is referred to Section 6.

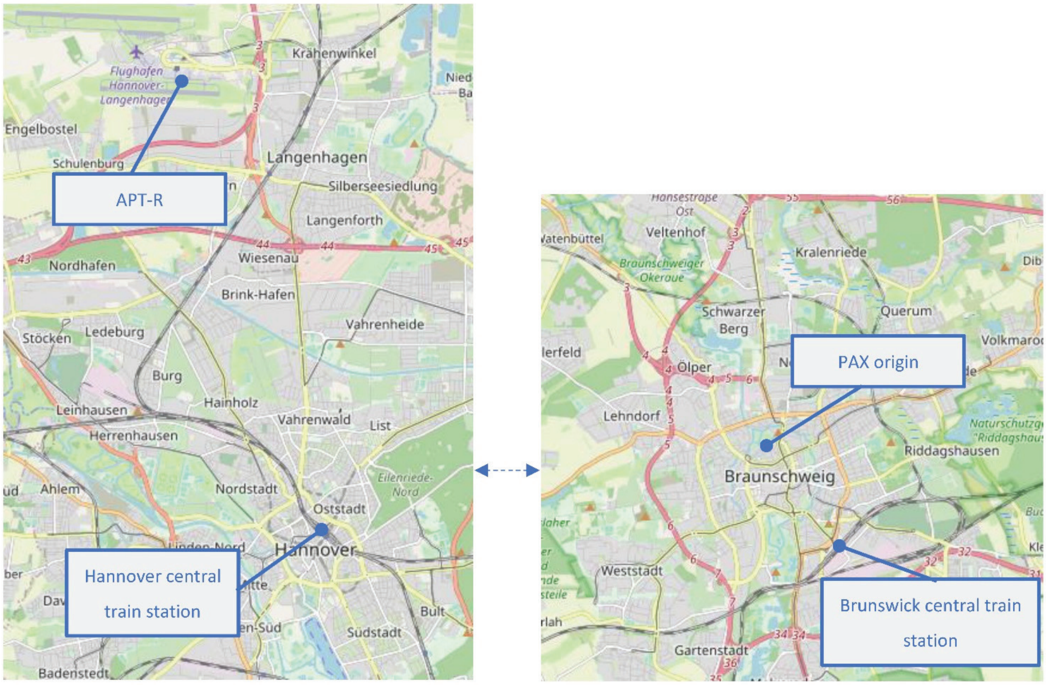

Figure 2. Regional airport area model (GIS layer)—D2A.

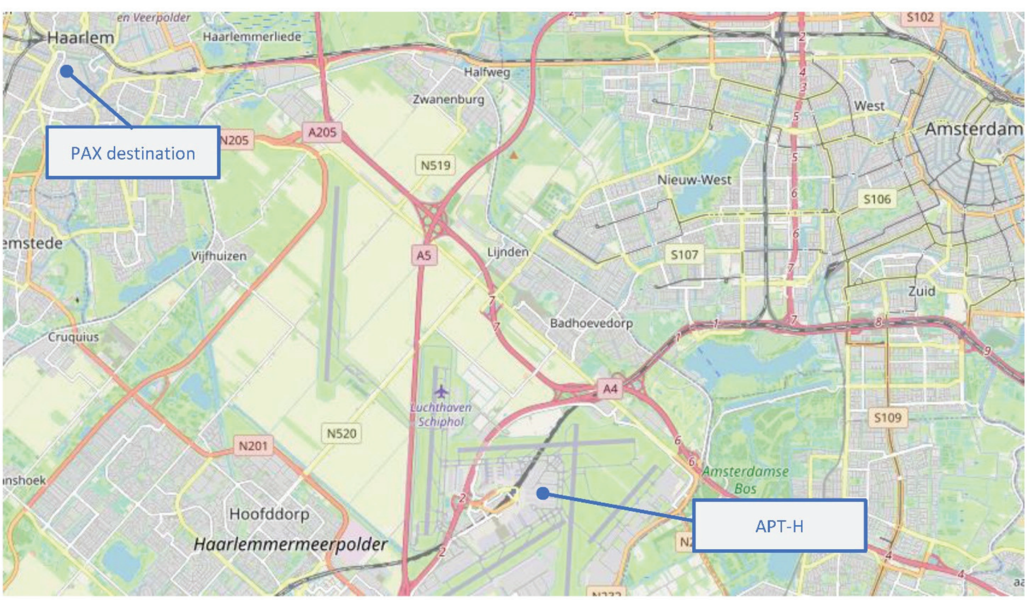

Figure 3. Hub airport area model (GIS layer)—A2D.

5. Passenger Profiles

Passengers and their expected behaviour are based on the distinction between business travellers (profile B) and other travellers, such as visiting friends and relatives (profile V). Their characteristics and corresponding expected behaviour are projected in the future according to three time horizons: 2025, 2035, and 2050. These characteristics were based on extensive research on political and economic trends, strategies defined by the EC (goals planned to be achieved in given time horizons), expected future passengers' needs, and technologies planned to be available in the target time horizons [52]. It is worth emphasising here that the X-TEAM D2D analysis of passengers' needs is based on the consideration of EU principles of equality and human rights to access public services, on the achievement of a set of passenger-related data to be combined with ATM and other transport means data for an affordable, accessible, and seamless multimodal travel experience, and on the meaningful profiling of multimodal and air transport passengers from the users' perspective. In addition, the designed profiles have been validated thanks to the support of the project-appointed Passengers Advisory Group, including several stakeholders. The considered use cases are "ATM-centred" (including the role of ATM in multimodal transport), using available air connections in a given time horizon.

Nevertheless, as the project's focus is up to the regional level, in the case of the traditional hub or regional airports, only access and regress to/from the airport are considered. In addition, the use cases focus on irregular multimodal travels (other than, i.e., daily travel to work or school) to better suit the integration in the multimodal network of also on-demand transportation alternatives, such as UAM vehicles, for instance. The detailed foresight scenario analysis carried out in the project has been documented in references [52,55].

Within the same time horizon, variability derives from different abilities associated with different classes of travellers (younger travellers are expected to not have limitations, whereas older people, typically over 65-years-old, typically experience some limitations) and from the different needs arising from the different natures of the trip (typically, business travellers have different needs and budget limitations than leisure travellers). In addition, for the same kind of traveller and the same kind of trip, the variability among different time horizons derives from the different technologies and service possibilities, which will evolve according to the results of the dedicated studies carried out in the project and reported in documents [52–56]. These profiles and scenarios take properly into consideration, for instance, that in the future, in the EU, the percentage of older adults is projected to increase. However, at the same time, the environmental sensitiveness and the technologically driven automation possibilities will evolve. Finally, it is worth noting here that profile V (other travellers) inherently provides an inner variability that assures including in the considered use cases and profiles as wide a consideration as possible of different needs and expectations because this profile includes both younger and older travellers. The resulting profiles, where the variability of the different needs according to the different ages and classes of the passengers is emphasised, are summarised further. Table 1 overviews the assumed profile B characteristics and corresponding behaviour, while profile V travellers are presented in Table 2. More details about assumed passenger profiles and their evolution across time horizons can be found in [52].

Table 1. Business traveller profile's key points assumed across time horizons.

Business Traveller (Profile B)	2025	2035	2050
Travel alone (mainly)	✔	✔	✔
Time constraints/target times	✔		
Budget limits	✔	✔	✔
A short stay and small luggage	✔	✔	
Might need to work during the travel time	✔		
Frequent flyer/traveller	✔	✔	✔
Adult (18–70 years), generally in normal health condition (no physical or sensorial impairments)	✔		
Can be allowed or not allowed to arrange/rearrange his travel plan depending on internal procedures	✔		
Expects a very high comfort standard		✔	✔
Expects a very short travel time		✔	✔
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 method constraints)		✔	✔
Full flexibility for travel plan changes		✔	✔
Might travel for long stays with large/heavy luggage			✔
Adult (18–75 years) with possible physical or sensorial impairments			✔
Must comply with environmental performance targets set by their company			✔

Table 2. Other travellers' profile's key points assumed across time horizons.

Other Travellers (Profile V)	2025	2035	2050
Travel in small or larger groups (mainly)	✔	✔	✔
Unless specific travel reasons (a ceremony, family issues, etc.) have relatively low time constraints	✔	✔	✔
Have budget limits	✔	✔	✔
Can have larger/heavy luggage or other items such as sports equipment, walking aids, etc.	✔	✔	
Might need assistance (children, elderly, disabled people)	✔	✔	✔
Can be or not be 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	✔	✔	✔
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	✔		
No constraints for reservation or payment methods		✔	✔
Sensitive to environmental footprint of their journey		✔	✔
No communication limitations thanks to technology support		✔	
Only personal items/small luggage as luggage will be picked up and delivered door to door (except for walking aids/stroller)			✔
Frequent short-stay/medium-distance travels			✔
No communication limitations (owing to good education and/or technology support)			✔

6. Experimental Set-Up

The simulation experiments considered the complete D2D journey under three time horizons—2025, 2035, and 2050—giving a total of two groups of nine scenarios. The state of the transport network in each time horizon was:

- No disturbance or normal operations; all transport operates according to its schedule, if applicable.
- An ad hoc disturbance occurs on one of the transport modes when the passengers are on their way to use it.

- A disturbance occurs five hours before passengers start their trip on one of the transport modes.

Each experimental scenario simulated 24 h of passengers travelling in Europe from Brunswick in Germany (where a regional airport is in place) to another country, Haarlem in the Netherlands (where a hub airport is available). A combination of real data and expected performance (based on reports from manufacturers) was used to make the scenarios as realistic as possible. The transport modes simulated in 2025 represent transport options available for passengers in Germany and the Netherlands in 2020 and 2021. During the journey, passengers used the available transport modes in the following way.

6.1. Scenarios in 2025

A multimodal journey must be planned and managed by the travellers. Planning can be done with the use of online services provided. Buying tickets in advance is possible, checking in at least the day before the flight, and using remote ticket validation systems. Flights are booked via a travel agency app or the internet in advance. In case of disruptions on one of the transport modes, the passengers must replan the journey on the spot and must switch to available alternatives within their budget. Figure 4 schematically shows the assumed journey of business passengers and other travellers in 2025.

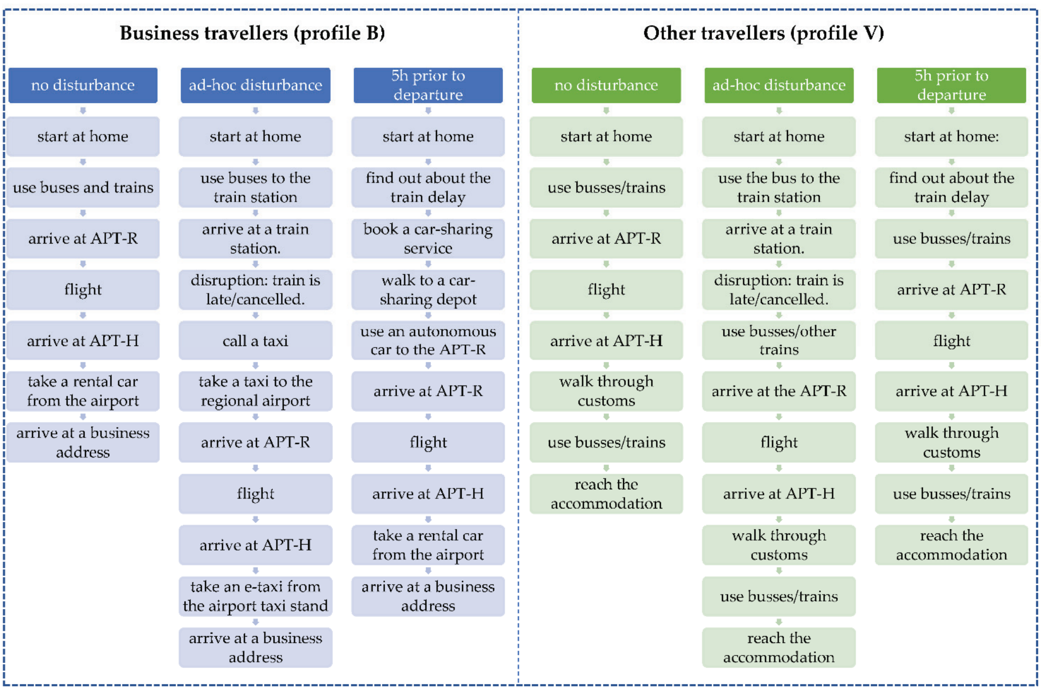

Figure 4. Travellers' journeys in 2025.

6.2. Scenarios in 2035

The exchange of information between air transport and surface modes, together with access and communication with the user's portable device, provides the travellers with all data concerning their multimodal journey in advance (at least a day before the day of the journey). The travellers are provided with alternatives, allowing them to react in time (concerning their requirements, e.g., related to disabilities). Privately generated data will be available for service providers, and daily demand forecasts will become possible, making the transport system more efficient and sustainable. The travellers have the possibility to modify their journey a day before travel (select other modes according to their preferences). Travellers will be offered to purchase one single ticket for the entire journey with access rights to change modes. Check-in is done automatically at the start of the journey. Owing to technology development, more users' focus will be on personal needs, as well as the impact on the environment.

Information about disruptions (e.g., delay) will be available for the travellers in a very short time, and if necessary, the travellers will be provided with available alternatives (in respect to their requirements, e.g., related to disabilities). This allows the travellers to react in time. In case of a lack of alternatives, the travellers will have to manage disruption by themselves using mobile applications providing data gathered from transport operators. The journey's structure in 2035 for travellers is shown in Figure 5.

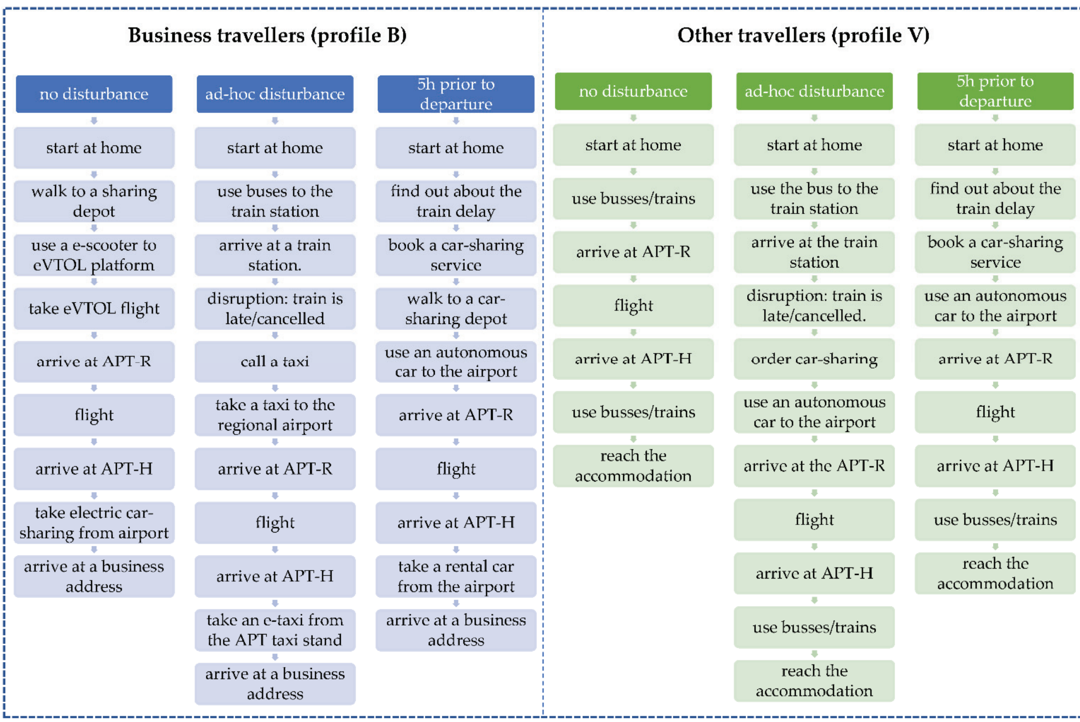

Figure 5. Travellers' journeys in 2035.

6.3. Scenarios in 2050

Travellers are provided with all data concerning their multimodal journey at least every hour during the journey. It is possible to modify the journey even on a day of the journey (select other modes according to their preferences). Travellers purchase one single ticket for the entire journey with access rights to change nodes. The offer will be designed based on smart pricing favouring preferred/prioritised modes of transport (regarding applied policies such as 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 management system approach applied (System of Systems management). Completed digitalisation will allow travellers to make the transport mode fitter to their individual preferences/needs: Next door is an NMS service, including e-bikes/e-scooters and an electric autonomous car-sharing depot.

In 2050, there is no difference for the traveller between disruptions five hours prior to departure 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 the required actions on their side. The travellers will have the possibility to modify their journey the day of the journey and select other modes according to their preferences/needs.

Disturbances in 2050 with internal reasons such as 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. Figure 6 presents the steps of the journey in 2050 for business and other travellers.

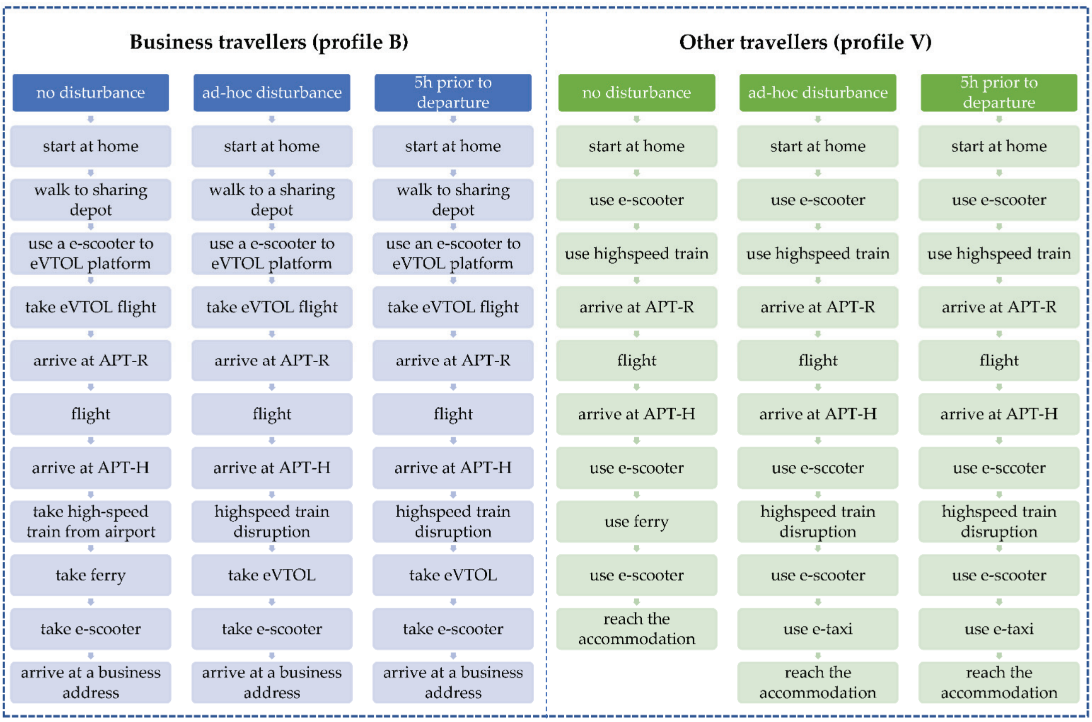

Figure 6. Travellers' journeys in 2050.

6.4. Experimental Assumptions about Passengers

Different passengers have different needs and expectations, resulting in multimodal transport systems performing differently depending on the specific passenger type using the service. To represent such differences, different groups of passengers were simulated with different walking speeds. The speed varied according to age, physical and sensorial ability, gender, number of group members, and many other variables [52,60]. These speed characteristics were adapted from [61], as listed in Tables 3 and 4.

Table 3. Profile B passengers' composition and walking speed assumptions.

Business Passenger Category	2025	2035	2050	Walking Speed, m/s
Older than 65	6%	9%	25%	Normal (1.18, 0.251)
Younger than 65	94%	91%	75%	Normal (1.445, 0.217)

Table 4. Profile V passengers' composition and walking speed assumptions.

Other Passenger Category	2025	2035	2050	Walking Speed, m/s
Without children and younger than 65	65%	58%	46%	Normal (1.445, 0.217)
Older than 65	19%	25%	32%	Normal (1.180, 0.251)
With children and younger than 65	10%	9%	12%	Normal (1.215, 0.188)
With impairments	6%	8%	10%	Normal (1.175, 0.304)

Furthermore, other assumptions were made regarding the number of passengers in each group and their journey starting times. These assumptions are listed in Table 5.

Table 5. Experimental assumptions for generating passenger profiles in 2025, 2035, and 2050.

Feature	Profile B	Profile V
Maximum number of PAX groups generated	1000	1000
Time between PAX groups, min	Uniform (0, 30)	Uniform (0, 30)
PAX group arrival rate, PAX groups	Uniform (0, 10)	Uniform (0, 10)
Number of people in PAX group	1	Uniform (1, 4)
First PAX group starts their journey	05:00	07:00
Last PAX group starts their journey	23:00	20:00

6.5. Experimental Assumptions on Transport Modes

Different modes of transport were modelled for various travel options considered in the coming decades. A set of informed modelling assumptions (evaluated by subject matter experts) was defined for each scenario. Where possible, the operational characteristics of mobility services were adapted from the corresponding service operators [62–66]. The following assumptions are considered in the experiments:

- 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).

Furthermore, for air transport, the following parameters are adopted:

- Flight Hannover–Amsterdam always departs at the scheduled time.
- Flight Hannover–Amsterdam's schedule corresponds to the schedule in 2021 [67].
- Embarkment on the aircraft always ends 20 min 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 the 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.
- Additionally, road transport was simulated under the following parameters:
- Since currently there is no information regarding the future design of road networks in Germany and the Netherlands, 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 in direct proximity to PAX origins.
- Boarding/de-boarding an e-scooter takes five seconds per person.

For railway transport:

- The railway infrastructure and its stations' locations 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 [65] and German Railways [66].
- Water transport operations:
- Water transport operates under speed regulations and uses navigable inland waters existing in 2020 in the North Holland province of the Netherlands [68].
- Ferry boarding/de-boarding takes five seconds per person.

Assumptions considered for simulating travel in 2035 and 2050 are presented in Table 6. Other mode-specific and detailed overviews of assumptions for each time horizon can be found in [60].

Table 6. Experiment assumptions for transport modes in 2035 and 2050.

Mode	APT Type	Capacity of One Unit	Average Speed, km/h	Arrival Mode	Interarrival Time, min	Activity Radius, km/ Ride Duration, min	Availability
e-scooter	APT-R	1	50	on-demand	-	Uniform (5, 15)	-
eVTOL	APT-R	4	200	on-demand	-	Uniform (10, 15)	-
HST B-H [1]	APT-R	391	200	schedule	~29 min	-	2:36–00:20
HST H–APT-R [2]	APT-R	391	200	schedule	30	-	04:35–01:33
flight	-	75	-	schedule	06:00 11:25 18:15	Uniform (45, 65)	-
ferry	APT-H	50	60	schedule	10	19.2 km	05:00–01:00
e-scooter	APT-H	1	50	on-demand	-	-	-
e-taxi	APT-H	1 person/group	Uniform (50, 57)	on-demand	-	Uniform (19, 23) km	-

[1] Highspeed train Brunswick–Hannover centre. [2] Highspeed train Hannover centre–Hannover airport.

7. Results

The following figures present the main results. We focused on the evolution in the quality of passenger travel in the expected horizons. Figure 7 presents the outcome for travel distance.

In the scenario without disturbances across time horizons for business travellers (Profile B), it can be noticed that, in 2035, disturbance on one of the transport modes results in the need to cover a 3% longer distance on the same route compared with 2025. The situation will improve by 2050, as this type of passenger travels only 1% further in 2050 compared to 2025. However, in the case of disruptions in 2050, the total travel distance could be reduced by 2% compared to 2025. Furthermore, in future disruptions in 2050, business travellers will take advantage of the multimodal transportation system and can shorten their total travel distance by 3% compared to the scenario without disturbances. This outcome reveals the resilience developed with the use of novel technology.

For regular travellers (Profile V), it can be noticed that multimodal networks generally reduce the travel distance required to reach the destination by 2% in 2035 and 2050. In case of ad hoc and early disturbances, other travellers can benefit significantly from the multimodality and decrease their travel distance by 1% in 2035 and 10% in 2050.

Regarding Figure 7, presenting the impact on total travel distance, in general, when there is a disturbance, the distance could be increased in some cases (in 2035). However, the passengers are forced to use a faster (and probably more expensive) mode to reach their destination. In this study, we did not consider economic factors; however, the results reveal that it could be an interesting indicator to consider so that the balance between efficiency and cost is more transparent.

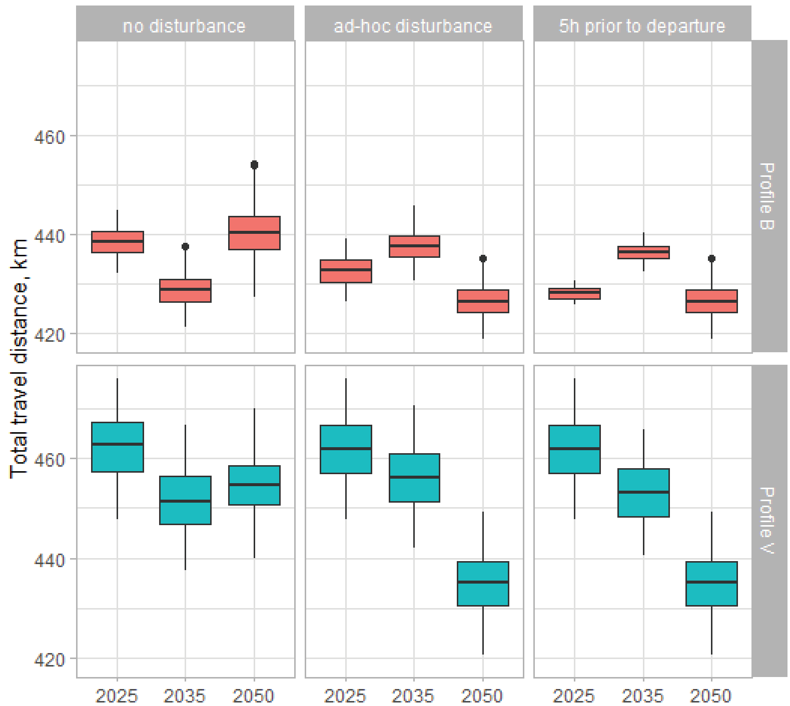

Figure 7. Total travel distance (including flight segment).

Regarding the average speed of travel (Figure 8), it can be noticed that in 2050 the travel speed will increase by 21% on average for both passenger profiles. Notable is that in 2035 disruptions slow the travelling of business passengers. However, in 2050, disruptions no longer impact their average travelling speed, revealing that the system becomes more resilient with the implementation of novel technology providing better options.

Another indicator considered is total travel time per passenger. Figure 9 illustrates that the system evolves toward reducing total travel time for both categories of passengers, as there is a clear tendency to reduce travel time as we approach 2050. It is important to note that, in the case of disruptions, the total travel time is not affected for both types of passengers. This might be another indicator of the system's resilience, as it can absorb the disruptions without affecting the passengers.

Furthermore, it is also important to mention that, for the first time, we can estimate what the total travel time D2D could be when the new transport modes are available. An average of 6.5 h can be expected for regular passengers in 2050 under normal conditions; for the case of business passengers, we can expect an average of approximately 6 h. In the case of disruptions, these values are reduced, as the passengers are forced to take speedy alternatives to avoid missing their flights. In extreme cases, we notice that the trajectory can be made in 2.5 h by business and regular passengers.

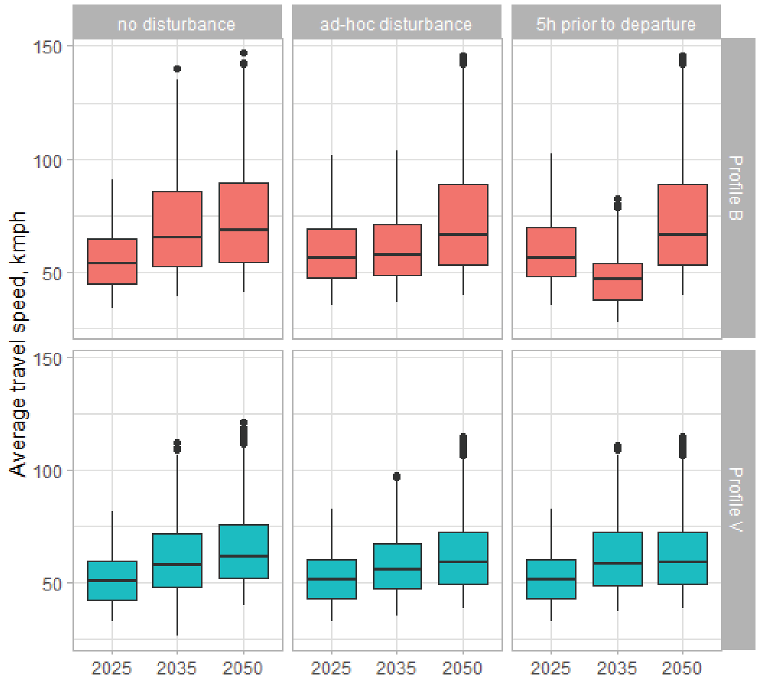

Figure 8. Average travel speed statistics (including flight segment).

Figure 9. Total travel time (including flight segment).

8. Conclusions, Limitations, and Future Work

In this paper, we presented a simulation framework that enabled us to construct a complete door-to-door journey in Europe for the first time. We used a simulation-based framework to investigate the impact of future transport modes under the European project X-Team D2D where future transport technologies for passengers' travel are considered. We devised performance indicators that can also be considered as proxies for resilience, level of service, or environmental emissions. The evaluation of the complete journey gave us the first insights into how the transport system can evolve in the future and obtained initial values of its performance indicators.

According to the results, as the system's integrations evolve towards 2050, the following conclusions can be drawn considering the two main categories of passengers in the study. First, with regards to total travelled distance, we can perceive a reduction in the travelled distance in the future for regular passengers, and this is more evident in the scenarios with disruptions. The reason for this might be that, under those scenarios, the passengers are forced to use alternatives that are more direct than public transport (the no disruption scenarios). In the case of business passengers, the impact is not as high; this might be because they are assumed to use the fast alternatives that reduce the travelled distance the most.

Regarding average travel speed, a positive trend is noted as time evolves and new and faster technology is incorporated into the system. This is evident as, for instance, passengers' travel speed is increased by 21% compared to today's transport networks.

Concerning total travel time, we can infer from the statistics that the impact of new technology on the transport systems is positive, and the travel time is reduced. In both categories, but more evident in the general population (Profile V), there is a clear trend towards reducing travel time. Furthermore, using this indicator as a proxy for the system's level of service or resilience (in the scenarios with disruptions), we can conclude that the level of service will be improved with new systems and alternative transport modes. With regard to resilience, since the total travel time in the disrupted scenarios is not negatively affected, we can conclude that the resilience of the system is improved.

The presented study has some limitations, since the scenarios combine real actual data from the current systems and expected performance in combination with informed assumptions (particularly those for the scenarios of 2035 and 2050). We would expect some inaccuracies in the obtained values, but in any case, they can be treated as an upper bound of the real situation if the system in place is similar to the one presented in the study. We would also revise assumptions such as passengers arranging and planning their trips in advance or the time spent in the airports in the future; furthermore, algorithmic governance was not considered in the study, and that could positively impact the performance of systems (especially in 2050).

In future work, these elements will be revised, and we will focus on the extreme cases in which the performance was the best to understand which conditions are fulfilled to make the journey more efficient. We will use the framework to investigate further door-to-door travel, as how the 4 h door-to-door travel is achievable in the future is an interesting question.

Author Contributions: Writing—original draft preparation, M.B.; writing—review and editing, M.M.M.; writing—review and editing, V.D.V. All authors have read and agreed to the published version of the manuscript.

Funding: This paper presents findings of the X-TEAM D2D project, which was funded by the SESAR Joint Undertaking, grant number 891061, under the European Union's Horizon 2020 research and innovation program.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding authors. The data are not publicly available due to the data management policies of the X-TEAM D2D consortium partners.

Acknowledgments: The authors would like to express their gratitude to the Dutch Benelux Simulation Society (www.dutchBSS.org (accessed on 15 July 2022)) and EUROSIM for disseminating the results of this work.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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Public Acceptance of the Use of Drones in City Logistics: A Citizen-Centric Perspective

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Abstract: The specific use of drones for city logistics has been increasingly studied and analysed by research and industry. An examination of the findings in the literature indicates that drones have proven to be a useful and added-value tool in the most diverse fields. However, the importance of the citizen's perspective has still not been sufficiently incorporated into the deployment of urban air mobility systems. This paper seeks to contribute to a better understanding of the interaction between public knowledge and the awareness of, and engagement with, drones, alongside the concerns and support for their use in city logistics. A survey was carried out in Portugal of the citizens with a view to better understanding their attitude towards such a goal. The survey revealed a positive attitude towards the use of drones in city logistics and that socio-demographic characteristics, namely gender, education level, job occupation, age, and home location are not directly correlated with citizens' attitudes. Moreover, citizens revealed that they favour a potential environmental benefit over a reduction in delivery time, which they would be willing to pay for. The policy implications derived can help develop the knowledge of public perception about drone usage for transport-related tasks.

Keywords: door-to-door transport; urban air mobility (UAM); advanced air mobility (AAM); city logistics; public acceptance

Citation: Melo, S.; Silva, F.; Abbasi, M.; Ahani, P.; Macedo, J. Public Acceptance of the Use of Drones in City Logistics: A Citizen-Centric Perspective. *Sustainability* **2023**, *15*, 2621. https://doi.org/10.3390/su15032621

Academic Editors: Vittorio Di Vito, Gabriella Duca, Raffaella Russo and Marilisa Botte

Received: 29 June 2022
Revised: 24 January 2023
Accepted: 29 January 2023
Published: 1 February 2023

1. Introduction

Individual online shopping habits have changed, forcing manufacturers and retailers to adapt their services to new demand requirements and leveraging the widespread use of technology and customer data [1]. The growth of e-commerce, aggravated by the lockdown, has transformed the distribution of goods [2] and has led to rapid and on-time delivery by a larger number of vehicles in urban areas [3,4]. E-commerce has proved throughout the pandemic its ability to adapt to customer-centric services and this has led to increased profitability, the expansion of customer bases, and added-value alternatives in ordering goods [5–7]. The increased complexity and variety of demand processes, boosted by e-commerce, have led retailers and logistics operators to offer a wider range of delivery channels and solutions that ensure faster, cheaper, and more flexible services [8]. Added to this challenge, in which the main structure is mostly achieved through digitization [9], operators must keep a competitive edge in the sector through increasing incorporation of emerging vehicle technologies and methods that meet the European Commission's environmental targets.

Due to the growing number of goods vehicle movements in urban areas, intensified by the ever-increasing trade volumes of e-commerce, modern cities are facing congestion, lack of public space, and relevant impacts of air pollution and noise. Moreover, customers have small-package delivery demands and different availability schedules widely distributed spatially, which makes last-mile distribution a complex issue and a bottleneck for traditional freight transport. Under such a scope, conventional vehicles, such as vans and trucks, are no longer entirely appropriate for delivering packages to individual customers in urban areas. To cope with this situation, technological innovations able to raise vehicle energy efficiency are required along with the implementation of new technologies and engines for clean road transport.

The increasing request for new vehicle technologies and driverless vehicles for last-mile deliveries is contributing to the emergence of uncrewed aerial vehicles (hereinafter referred to as drones), correlated to e-commerce-sourced deliveries [7]. Although the feasibility and legislative approvals of these solutions are still being explored and analyzed [10], cargo drones are already being manufactured and the technology is being upgraded to respond to operational requirements [11,12]. Cargo drones can carry small-sized and lightweight packages in response to the smaller, fragmented, and frequent deliveries generated by e-commerce [7,13]. The lower aggregation of demand results in an increase in the number of vehicles in circulation, the distance traveled, and, consequently, the operational energy requirement and related environmental burdens [4]. In extreme situations, emerging vehicle technologies and the replacement of vans that are poorly consolidated can play an important role in optimizing the system benefits from both an environmental and economic perspective [7].

In addition to the technological and operational challenges, cargo drones must also deal with the crucial factor of social acceptability. Social acceptability relates to the public perception of the positive and negative impacts of the solution in their lives. A range of factors can affect public perception, namely privacy issues, security, safety, public disturbance, cost, environmental pollution, and economical effects [14]. As stated by [15], the form that drones will be adopted in city logistics, as well as respective regulation, is still to be determined and, therefore, there is not enough precision on the volume of traffic likely to be generated, operating parameters, and locations of the respective supporting infrastructures. The lack of a clearly defined supply or delivery system renders it impossible to identify citizens' concerns, as it is not clear what policymakers are asking the public to accept [16]. To fill this gap, it will be necessary to carry out studies and implement initiatives that allow for better knowledge of non-expert attitudes toward the policy under assessment.

This paper attempts to analyze the public perceptions and responsiveness regarding the use of cargo drones for moving toward low-carbon logistics. The work is supported by a survey that explores the perspective of non-experts as to the future integration of drones into transport systems.

The remainder of the paper is organized as follows. Section 2 provides a review of studies on the application of drones in city logistics, under heterogeneous approaches that include both the technological perspective (including competitiveness and an operational and environmental assessment) and the social acceptability reflecting the perception of citizens towards the emerging solution. In Section 3, a survey on the citizens' perspective on the use of drones for home deliveries is presented, followed by the respective analysis in Section 4. Finally, Section 5 concludes the paper by presenting the policy implications derived based on public perception of drone usage for transport-related tasks.

2. Literature Review

Research and industry have looked at the potential applications of drones in a wide variety of fields and market niches with the aim of meeting civic and industrial challenges. Most of these systems are still in the early stages [15] but the advances and continual development of drones open up considerable potential and opportunities for application in many areas [17]. The diverse drone applications have in common the ambition of developing an autonomous flight system that will reduce the cost, time, labour level, and/or complexity of operations [18]. Applications include, among others, the use of drones for inspection of power facilities and structures [19,20], archaeological prospection [21], agricultural and farming [22], conservation, surveillance and monitoring [23], humanitarian logistics [24,25], emergency care and deliveries [26], security/disaster management [27], and finally, the focus of this paper, parcel and cargo deliveries [28,29]. The corresponding literature is detailed and documented and presents a wide heterogeneity in terms of optimized objectives, solution methods, applications, and constraints.

The specific application of drones to city logistics has been increasingly studied and analyzed by academic research and industry [30]. From the operational perspective, as drones can maneuver and have autopilot and autonomous capabilities, such technical variations can affect the results of studies, which are dependent on the assumptions on technical capabilities, namely in what refers to the competitiveness with other modes of transport, varying levels of operational feasibility [31]. The authors in [27] state that the potential of drones can be increased when combined with other modes of transport, an argument that is also supported by [32], who present a review on the delivery with drones and state that joint deliveries with trucks and drones yield higher flexibility in terms of delivery systems and decrease delivery times and associated costs. When comparing the costs of trucks and drones, [33] estimate that the cost savings of delivering vaccines by truck exceed the fixed cost required to create a drone infrastructure for that purpose. These outcomes are dependent on technical assumptions, about which there is a considerable lack of practical validation. Despite the considerable level of uncertainty regarding operational feasibility, technical competitiveness with other modes of transport, and market conditions, the industry is testing drones (e.g., Amazon) with a view to increasing customer satisfaction by reducing delivery times and costs [32].

The European Commission's environmental targets have led academic research and industry to pursue the integration of crucial concerns with respect to environmental assessment. Similarly, to what is observed in the technical feasibility studies, the assessment of the impact of drones on the environment can lead to dissimilar results biased by the chosen variables and assumptions from the performed analysis [34]. In [34], the author quantifies the potential effectiveness of drones for reducing CO2e lifecycle emissions in comparison to conventional diesel vans, electric trucks, electric vans, and tricycles (including both the utilization and vehicle production phases). Results indicate that drones are more CO2e efficient for small payloads than conventional diesel vans on a per-distance basis. Considerably different results are obtained when customers are grouped in a delivery route. In such conditions, drones are not more CO2e efficient than tricycle or electric van delivery services. In [35], the author compared the energy consumption of drones with diesel and electric trucks in a unimodal distribution system and through simulation, concluding that, for areas with high customer density, drones have a higher energy consumption than diesel and electric trucks. In the exceptional cases of rural and low-density demand areas, drones proved to have a slightly lower energy consumption. This analysis was based on the drone mission profile and, consequently, the energy assessment refers to the energy used throughout the operation, excluding variables and processes prior to that stage. The authors in [36] also studied greenhouse gas emissions and energy demand for package delivery drones and showed that deployments of drones can reduce greenhouse gas emissions if carefully deployed as an environmentally friendly alternative to traditional distribution and delivery methods. They highlight the importance of and need for more standard and systematic analysis in order to perform a more consolidated analysis on the topic, given that, when including the full drone delivery life cycle in the analysis, the delivery operation leg has the smallest environmental impact whilst most of the emissions result from other stages, such as the production of the drone parts [37].

The variability of the results described in the scientific references reflects the lack of consolidated arguments with respect to the competitiveness of drones vis-à-vis other modes of transport, operational feasibility, or environmental benefits. However, these are not the only fundamental factors that must be considered prior to the deployment of drones for cargo logistics purposes. The authors in [38] identified, categorized, and prioritized barriers to implementing drones within city logistics. These authors were able to identify regulations, privacy and security threats, public perception, environmental issues, technical aspects, and economic aspects as the main barriers to the implementation of drones for cargo logistics. Policy regulation was the most critical obstacle, with the economic aspect revealed to be a less critical factor. Regulations restrict the parameters for drone operations, limiting them to certain airspace zones, and also set limits in terms of proximity to infrastructures and citizens while ensuring safe compatibility with air traffic, which can reduce the convenience of their usage. Regulations are also the most effective tool for guaranteeing that public perception is considered in the operation of drones [33]. In [28], while also looking at potential barriers and problems, respective solutions, and the expected benefits of drones for parcel and passenger transportation, the authors concluded that social benefits and public involvement should be the basis for the deployment of drone systems. Recent studies have explored public involvement in both a range of drone applications and specific use cases and indicate concerns that focus on privacy and safety, and differences have been observed in levels of acceptance by different demographic and stakeholder groups [15]. The authors in [39] present a survey on the public acceptance of drones in Germany, reaching the conclusion that citizens were not in favor of utilizing drones for public leisure, package delivery, or advertising but they approved using drones for research, rescue missions, and civil protection. The research in [40] had similar results when the authors carried out a survey in Singapore. They concluded that applications such as search and rescue, wildlife reserve management, disaster management, and monitoring atmospheric conditions have a higher acceptance rate, while there was a lower support rate for moving people, videography, and issuing speed and car park tickets.

Moreover, examination of the findings in the literature would indicate that, although numerous papers have recently been published in which drones have proven to be a useful and added-value tool in different fields of application, the importance of the citizen's (and non-expert's) perspective is still not sufficiently incorporated into the deployment of urban air mobility systems [41]. The literature review presents outcomes regarding competitiveness with other modes of transport, operational feasibility analyses, and environmental assessment practices, although most of those results refer to technological issues. The deployment of drones for cargo logistics is not a merely technological challenge analyzed by technical experts; citizens (non-experts) must reflect their attitude and acceptance towards such a solution in order to provide guidance for authorities to translate those concerns into regulation. This paper seeks to contribute to a better understanding of the interaction between public knowledge, awareness, and engagement with drones, and the concerns and support for their use in city logistics. The policy implications derived can help develop the knowledge of public perception about drone usage for transport-related tasks.

3. Citizens' Perspectives on the Use of Drones

Research on public acceptance tends to take place in the post-commercialization phase of new technology when public concerns begin to emerge. Therefore, it is needed to encourage the proactive effort to identify public perceptions and values prior to commercialization when strategic decisions have not been made and the public can participate in the research and development process. Public acceptance should be ruled by three typical principles: (a) public knowledge, (b) awareness, and (c) engagement. Public knowledge entails that information about drones should be communicated in a correct, user-friendly, and timely manner, and include, in a transparent manner, the key concerns and perceived risks surrounding the usage of drones and how legislative levels will include their concerns. The better people are informed about the possible risks, the more they accept the use of drones if the benefits outweigh the risks. Awareness means that there is a need for targeted outreach and public awareness efforts regarding the extended functionalities of drones and their capacities. Engagement means that the affected individuals are part of the policymaking discussion and can influence the decision-development process. All in all, attitudes of the public about drones, in general, are not stable and can easily be altered by how and when the subject is introduced. Asking people about their views on the acceptability of new technology such as drones is not only about obtaining their favorite technical features or perceived risks but recognizing that there are normative and political priorities as well.

3.1. Methodology

In this paper, the authors tried to explore the perception of citizens (non-experts) on the use of drones for city logistics through the implementation of an online survey. To the best of our knowledge, it was the first Portuguese survey on the topic.

The survey constituted 30 questions and was disseminated through online channels between 23 March and 9 May 2022. Questions were binary, not including the options of different levels of acceptance or agreement.

The questions of the survey were designed with the goal of shedding light, among others, on whether characteristics such as gender, education level, occupation, age, home location, and online shopping habits contribute to the attitudes of public perception on drones for city logistics purposes and if the perspectives of non-expert and expert individuals differ (in what refers to competitiveness, operational, and environmental aspects). The survey also tries to clarify what are the benefits and risks that citizens identify in such technology, whether they support public investment in operational infrastructure, and their acceptance of drones flying over their residential homes.

3.2. Participation and Survey Results

The sample was conducted online and, therefore, using random location sampling. The authors sent the survey to mailing lists and other online channels, reaching 2000 individuals. The response rate was 15%, with 300 respondents completing the survey. Results had a confidence level of 95% with a margin of error of 5.22%. In all, 80% of the sample was from the four most populated districts (Lisbon, Porto, Coimbra, and Aveiro). The widespread location of the respondents and the size of the sample do not allow us to unequivocally state that the respondents represent a specific residential district.

Some 45% of the sample are female and participants' age spanned from 16 to 62 years. Plus, 23% are aged between 16 and 21 years old (Generation Z), 58% are aged between 22 and 41 years old (Generation Y), 18% are between 42 and 61 years old (Generation X), and 2% are over the age of 62. In addition, 65% have a university education. A total of 42% are students and 43% work full-time with a contract.

In their responses, 42% of respondents prefer to go to a store to buy their products, while 24% prefer to do so online, and the remainder does not have a preference. There is no correlation between the preference in terms of online shopping versus physical purchasing and the respective education level of the buyer or their job/occupation. Respondents who do not buy online mostly choose that option due to a preference to visit the physical store (37%) and security concerns (18%). Respondents that buy online mostly do so for reasons of convenience (65%) and product diversity (43%).

A total of 90% of respondents stated that they bought products online in the last year and 45% of those were female. Some 92% of online buyers stated that they were satisfied or very satisfied with their online shopping experience. There is no gender correlation regarding the satisfaction level with online shopping.

A total of 84% of respondents who bought products online stated that they did so sporadically up to four times per year (40%) or irregularly up to once per month (44%). Some 12.5% buy online products at a frequency of once per week and 2.5% do so two or more times per week. A total of 67% of online buyers have a university degree but there is no direct correlation between the frequency of online shopping and the education level. Online buyers are mostly students (43%) and people working with full-time contracts (42%). Some 92% of students stated they buy sporadically or irregularly, whilst 81% of workers with a full-time contract have a similar frequency pattern. Some 85% of online shoppers purchase products through the brand websites, 51% stated that they use platforms such as Amazon and eBay to meet their demands, and 42% order on-time groceries and takeaways online. The share of online buyers that use hypermarket websites or apps is 21%, while 19% stated that they use C2C platforms, and 12% use marketplaces on social networks. Some 74% of online shoppers state that they used platforms to purchase clothes, shoes, and accessories, while 50% have bought technology and software. Books and music players were acquired online by 42% of the respondents, cosmetics by 32%, sports by 29%, home furniture and decoration by 17%, and pharmaceutical products by 12%. Online shoppers indicated that home deliveries are mostly carried out by vans (68%), motorbikes (26%), and trucks (19%). The significant share of motorbikes has to do with the increasing market for food delivery on demand.

As far as the use of drones to deliver cargo ordered online is concerned, 21% of female respondents were aware of this, while for men a more substantial share (50%) was registered. While 33% of respondents are aware of the use of drones in city logistics, no direct correlation was established between this knowledge and the respective education level. Students and workers on a full-time contract are those with greater familiarity with drones, although there is no direct relationship. Some 71% of respondents say that they would use drones for home delivery if that option existed at the same fee as the business-as-usual logistics fee. This share would significantly decrease to 45% if the service would be faster than other modes of transport but that implied an additional fee. Results revealed to be statistically highly significant, as $p < 0.001$, and are similar to the ones referred by [15], include a share of 64% of respondents supporting the use of drone deliveries. A higher percentage of respondents (69%) would accept paying an additional cost if the service were more environmentally friendly than other modes of transport and 66% would accept it in exchange for greater flexibility in choosing the delivery location and schedule. There is no direct correlation between this potential acceptance and the educational level or occupation. When trying to understand what the monetary fee for such a service should be, 24% stated they would pay up to EUR 0.99, 35% between EUR 0.99 and 1.99, 18% up to EUR 2.99, and 3% consider it would be worth more than EUR 3.00 per delivery. There is no direct correlation between this potential acceptance and the educational level or occupation.

Concerning the potential for public acceptance in cities, the survey asked if respondents considered that there were benefits of using cargo drones for cities and citizens. Respondents were also asked if they would accept drones flying over their houses with the purpose of delivering goods. Some 76% are of the opinion that drones for city logistics purposes can have positive impacts on cities and citizens, and 62% would accept drones flying over their homes in their area of residence. In addition, 70% of respondents say that traffic reduction is one of the main benefits of the use of drones in cities. A reduction in pollution is highlighted by 65%, followed by a reduction in delivery time, highlighted by 47%, and both noise and accessibility, highlighted by 29% for each. Despite recognizing the value for cities, only 52% believe that the infrastructure for drones should be built with public investment. There is no direct correlation between this potential acceptance and the educational level or occupation.

4. Analysis of Results

The survey characterized the respondents based on gender, education level, occupation, age, and home location. These characteristics were not identified as being representative in justifying the attitudes in terms of public perception of drones for city logistics purposes. Most of the respondents have a university degree, which can be explained to some extent by the fact that the topic of the use of drones for city logistics is still not a familiar one for a significant number of the survey recipients. The survey was disseminated online, which contributed to students and workers with a full-time contract, aged between 16 and 61 years old, making up the highest share of respondents.

More respondents prefer to buy their products at the store over online shopping, but one-third of respondents do not have a preference. Respondents who purchase products online are satisfied or very satisfied with online shopping but most are not frequent shoppers. Most online shoppers have a university degree and occupations that imply a more probable and frequent usage of smartphones and computers. The channels used for online shopping and reasons for online shopping are diverse but there is a preference for certain products, namely from the fashion and technology sectors. Moving such products using drones will depend on the intrinsic characteristics of the parcel to be delivered.

However, the significant share of current deliveries made by motorbikes, associated with small-weight parcels, can be an interesting niche for drone usage. Most respondents state that they would use drones for home delivery if that option exists without any additional cost when compared to the business-as-usual logistics fee. If the service were to be paid for, then respondents clearly value the environmentally friendly side of using drones more, as well as the flexibility of delivery that it can assure rather than the speed of the transport. This factor should be highlighted, as it differs from the perspective of experts, who value travel time as the basis for the competitiveness between modes of transport. The fact that respondents would accept paying for deliveries if this meant an environmental benefit, with many of them even opting for higher payments, would seem to reveal that if drones can demonstrate that they are less harmful to nature, their public acceptance could be higher.

In terms of the potential for public acceptance in cities, most respondents consider that drones for city logistics purposes can have positive impacts on cities and would accept the area of residence to have drones flying over their homes. The high acceptance revealed by respondents is higher than expected and seems not to value the visual intrusion and noise that have been identified as crucial points of discussion in similar studies. Despite recognizing the value for cities, respondents do not fully support public investment in building the required infrastructure for drones. Considering citizens recognize the benefits of drones for cities, such a position might reflect priorities in the perception of non-experts regarding public investment areas. However, as the survey did not specify the type of infrastructure needed to support the use of drones for city logistics, this can have an influence on respondents' perceptions about its magnitude and needed investment.

Overall, the survey results on citizens' views towards the use of drones for city logistics revealed a positive attitude towards this goal and revealed that the selected socio-demographic characteristics, namely gender, education level, job occupation, age, and home location are not directly correlated with citizens' attitudes.

5. Conclusions

The paper endeavors to provide a perspective from citizens, who are also non-experts, on the use of drones for city logistics. The survey revealed that citizens consider that drones for city logistics purposes can have positive impacts on cities and that they would accept drones flying over their homes in their area of residence. These results can form the basis for further actions from cities towards the integration of urban air mobility infrastructures in transportation networks, in line with the current environmental goals set by the European Union. The fact that urban space is limited on the ground and in the air makes it difficult to meet the needs of all stakeholders. The deployment of urban air mobility solutions must be user-centric, which in the case of cargo deliveries by drone, means having considerable knowledge of citizens' perspectives. The fact that while citizens recognize the benefits of drones for cities, they do not fully support public investment for building the required infrastructure, indicates that such activities are still not considered a priority or that the precepted magnitude of the investment is higher than the one that citizens are willing to accept.

Citizens perceive a potential environmental benefit that they are willing to pay for. Their focus is not on the delivery time but on the environmental harm or lack thereof. Added to the significant number of low-weight parcels delivered by motorbikes, this fact can represent a potential niche market for cargo drones.

Nevertheless, despite the originality of the results of the survey, namely with regard to the primary focus on the environmental benefit and the lack of a representative influence of the selected socio-demographic factors on the attitudes of citizens towards cargo drones, this study does contain a few limitations: Firstly, the empirical evidence is based on one region and results, and policy recommendations, could be different in other countries. Secondly, the survey dealt with the potential of drones for city logistics purposes only and did not correlate public acceptance with other delivery methods, accordingly, the results are only valid for this application. Thirdly, the survey quantifies the monetary effort that citizens are willing to make so that the service is environmentally friendly but did not establish how that result could be reflected in the drone design and technology development. Future research could aim at extending this present study with regard to the aforementioned limitations. Additionally, we propose the conduction of comparable studies in different locations and circumstances. From a methodological point of view, it would be interesting to take a more holistic approach and try to define how these results can be incorporated both into drone design and in terms of urban policies. Drones must be designed so that they are acceptable to the citizens, not the other way around.

Author Contributions: Conceptualization, S.M.; Investigation, F.S. and M.A.; Resources, F.S. and M.A.; Data curation, P.A.; Writing—original draft, F.S.,S.M., M.A. and J.M.; Writing—review & editing, S.M.; Supervision, S.M. and J.M.; Funding acquisition, J.M. and S.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research and APC were funded by the ASSURED UAM project, financed from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006696. This work was supported by the Foundation for Science and Technology (FCT)—Aveiro Research Centre for Risks and Sustainability in Construction (RISCO), Universidade de Aveiro, Portugal [FCT/UIDB/ECI/04450/2020].

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study, anonymity was assured. The participant's right to confidentiality was considered and they were fully informed about the aims of the research. Their voluntary consent to participate was recorded and respected legal requirements on data protection.

Data Availability Statement: Data is unavailable due to privacy.

Conflicts of Interest: The authors declare no conflict of interest.

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Integrated Door-to-Door Transport Services for Air Passengers: From Intermodality to Multimodality

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Abstract: Intermodal and multimodal door-to-door journeys refer to the usage of various transport modes (air, rail, bus, road or maritime) by the traveler to complete a single journey. The main difference between these two approaches is that multimodal transport is executed under a single transport contract (a single ticket) between the passenger, on the one hand, and transport operators, on the other hand. The benefits of this type of service are reflected in the potential to save time and money. Such systems would make the transport sector greener and more sustainable, promote growth and reduce carbon emissions. The purpose of this paper is to define the concept of an air passenger multimodal transport system, identify factors and challenges that determine such a system's development within Europe and to provide recommendations and directions for future research. The research carried out so far has indicated that market segmentation and transport system characteristics, as well as economic, social and political factors, have direct impacts on system development. This paper provides the basis for introducing single ticket, timetable synchronization and data sharing services, as well as the need to update the related regulations in order to move towards air passenger multimodality in both research and practice.

Keywords: multimodal air passenger transport; seamless journey; European transport market; door-to-door travel; data sharing

Citation: Babić, D.; Kalić, M.; Janić, M.; Dožić, S.; Kukić, K. Integrated Door-to-Door Transport Services for Air Passengers: From Intermodality to Multimodality. *Sustainability* **2022**, *14*, 6503. https://doi.org/10.3390/su14116503

Academic Editors: Vittorio Di Vito, Gabriella Duca and Raffaella Russo

Received: 22 March 2022
Accepted: 18 May 2022
Published: 26 May 2022

1. Introduction

The terms intermodality and multimodality have been used commonly with reference to freight transport. The systems termed as above have been designed and used with a view to providing more efficient, effective and socially and environmentally friendlier door-to-door freight transport by combining various transport modes in consecutive order [1,2]. In intermodal freight transport, there is a separate contract for each individual leg of the journey, and accordingly there is more than one entity responsible for the successful achievement of the transport. In multimodal transport, one contract covers the entire journey. One operator takes sole responsibility and ensures door-to-door delivery is completed, even if other operators are involved in the journey [3].

Any journey involving air travel is by nature intermodal due to the combination of the trip to the airport via surface modes and the trip by air. On the other hand, analogously to freight transport, multimodality could also be considered for passenger door-to-door transport. Namely, air passengers have to access the origin airport via different surface transport modes and their systems in order to join the air transport service. Upon completion of the air travel, these modes and systems are again used from the destination airport to the final destination. The achievement of seamless multimodal passenger journeys is one of the goals of the Transport White Paper, which aims to establish a common European multimodal transport system with the potential to ensure that each mode of transport is carried out in the most efficient manner (in terms of comfort, price, speed, flexibility, reliability, etc.). Multimodality in this paper will imply the coordination and integration of different modes of transport. In this context, the main attributes of the fully coordinated multimodal service are given in Table 1, together with the corresponding attributes in the case of an intermodal, non-coordinated or partially coordinated service [4].

Table 1. Non-coordinated or partially coordinated vs. fully coordinated transport service attributes [4].

Non- or Partially Coordinated—Intermodal Transport	Fully Coordinated—Multimodal Transport
Separate tickets	Single ticket
Timetables—non-synchronized arrival/departure times causing longer waiting times at transfer points	Timetables—synchronized arrival/departure times among transport operators, enabling shorter waiting times at transfer points
Longer walking distance between terminals during transfer due to current location of terminals and stops	Better location of terminals and stops—shorter walking distance between terminals during transfer
Multiple information sources	Single information platform
Responsibility of passenger or transport operator involved (each mode independently)	Responsibility of passenger or responsibility shared among transport operators involved
Luggage check-in at the airport	Possibility of remote luggage check-in
Access facilities (elevators, ramps, vertical and horizontal escalators, automated people movers)	Additional access facilities at transfer between terminals and stations for all modes of transport

However, despite the existence of intermodality, coordination between different air and surface transport modes and their systems is missing at the larger scale, indicating the lack of the real multimodality. In general, such multimodality implies providing integrated door-to-door services to air passengers via a single transport operator similarly to air freight logistics service operators providing their integrated door-to-door services (DHL, FEDEX, UPS, etc.), ref. [5].

The objectives of this paper are as follows:

- Elaborate on the developments of integrated air travel through shifting from intermodality to multimodality;
- Consider the multimodal service within the European market;
- Identify major factors that stimulate multimodal transport demands;
- Emphasize and analyze the challenges and opportunities for development of multimodal service;
- Provide recommendations and research directions to move towards future air passenger multimodality.

In addition to this introduction, this paper is organized as follows. Section 2 provide a literature review and indicates the contributions of the paper. Section 3 presents the air transport system with the main relevant transport phases. The research methodology is described in Section 4. Section 5 contains the main findings in terms of relevant factors, challenges and opportunities in multimodal service development, including recommendations for future policies. Finally, Section 6 presents concluding remarks and future research directions.

2. Literature Review

In the relevant literature and related work, the terms intermodality and multimodality can be found to have different meanings. These terms have often been used with ambiguity, although they refer to different transport service concepts. In most of the cited papers in Table 2, the use of more than one transport mode within a given period of time is referred to as multimodality. Therefore, this paper contributes by clearly stating the differences between intermodality and multimodality. Namely, as mentioned before, intermodal passenger transport is the existing transport service, while multimodal passenger transport, which indicates a fully integrated transport system (as described in Table 1), is the future service that should be achieved.

Table 2. Selected papers on multimodality.

Reference	Problem Considered	Case Study	Aspects of Multimodality
[6]	Factors relevant to any competition assessment of air–rail intermodal agreements.	Europe	Considers only the link between air and rail, door-to-door is not considered.
[7]	Travel trends among young adults: declining car travel demand and the understanding of 'peak travel'.	Germany	Limited to city transport, without air transport
[8]	The environmental impact of introducing a high-speed air–rail link.	Spain	Considers only the link between air and rail, door-to-door is not considered.
[9]	How the change in urban mobility cultures affects the variability of mode choice (from urban monomodality to multimodality)	Germany	Limited to city transport, without air transport (multimodality—using different modes of transport without coordination)
[10]	Ways to improve public transport services by using intermodal passenger transport.	Romania: Timisoara	Limited to city transport, without air transport
[11]	Evaluation of Urban Public Transport intermodal hub quality through level of service—total transfer time.	Russia: Moscow	Limited to city transport, without air transport
[12]	Relation between high level of multimodality and less car use	England	Considers only ground modes, multimodality—using different modes of transport without coordination
[13]	Model for estimation of full door-to-door travel time between two cities using either the train or the plane.	Europe	Considers only total travel time in the current intermodal system
[14]	Survey of real door-to-door travel times in long-distance traffic by air and rail	Germany	Considers only total travel time in the current intermodal system
[15]	Provision of effective transport services for vulnerable populations and areas and identification of methods to overcome these challenges.	General	Limited to city transport, without air transport
[1]	Intermodality is a key solution for sustainable cities in terms of societal changes and mobility trends.	Berlin, Paris, Copenhagen, Hamburg	Limited to city transport, without air transport
[16]	Survey on multimodal choice behaviors of intercity travelers (airplane, High Speed Rail-HSR, traditional train, and express bus).	China: Xi'an	Multimodal choice, not multimodal trip
[17]	Different approaches to information sharing, common situational awareness and real-time collaborative decision-making between airports and ground transport stakeholders.	Europe	Considers systems to help integration of different modes
[18]	Factors which influence service quality of multimodal transportation of a hub with different types of public transport: metro, bus and rail.	Anand Vihar, Delhi	Limited to city transport, without air transport
[19]	Walking time distributions for transfers from bus to rail platform are examined (based on smart card data and automatic vehicle location data).	Denmark	Considers only walking time between two modes, without air transport
[20]	A bi-level model for a multimodal network design problem is developed.	General	Without air transport

Table 2. *Cont.*

Reference	Problem Considered	Case Study	Aspects of Multimodality
[21]	Air–rail integration: causal relationship between passengers' psychological and behavioral variables; identification of different passenger groups for service improvement.	China: Shijiazhuang Zhengding International Airport	Considers only the link between air and rail, door-to-door is not considered.
[22]	Designing a personalized multimodal travel service to recommend a route based on individual preferences, and to improve its performance.	China	Limited to city transport, without air transport
[23]	A route choice model for a large-scale multimodal public transport network. Metro, urban rail, local trains, regional trains and busses are included.	Greater Copenhagen Region	Limited to city transport, without air transport
[24]	Sustainable integrated transport and reduced bottlenecks in PT infrastructure, increasing the capacity of existing transport services.	Albania, Italy, Greece, Bosnia and Herzegovina, Croatia, Serbia, Montenegro, Slovenia	Without air transport
[25]	Future urban air-taxi services—models and algorithms for pooling and scheduling and for routing and recharging; synchronization of different transport modes.	General	Limited to city transport

Considering the selected papers given in Table 2, it can be observed that the research has been mostly limited to the city transport and has not included air passenger transport. Few papers have considered only the link between air and rail [6,8,21], while only [25] took into consideration air transport, although this was for future urban air mobility rather than passenger air transport. Additionally, the importance of transport system integration and its advantages, as well as the importance of data sharing in such a system, are indicated in [22]. Furthermore, possible issues related to data security and privacy are pointed out, but without proposing a solution. It should be noted that [17] also investigates data sharing with a focus on systems to help in the integration of ground modes and air transport. In order to fill the gaps in the literature, our approach considers different aspects of air passenger transport integration into a multimodal system.

3. Air Passenger Journey

Air passenger journeys are realized through five phases, from planning to ending, as shown in Figure 1.

Figure 1. Simplified scheme of the five phases of air passenger journey.

As can be seen, every journey begins with the planning phase when passengers consider their travel options before making a decision. This is followed by the phase of booking and purchasing tickets, when air passengers consider the available travel options related to the airlines and their services (time of departure, direct vs. indirect flights; other service attributes, such as priority boarding, extra legroom, lounge access, etc.), make a choice and purchase the service [26].

During the airport access phase, passengers mainly consider the selection of access transport modes and their systems in terms of availability, travel time and cost [27]. Airports and airlines can provide passengers with a variety of pre-flight and in-flight services, respectively. Airports usually deal with service quality by providing shuttle services, improved parking facilities, restaurants and shops [28]. Airlines provide online check-in and text messages and email notifications about flight delays and changes. Moreover, airlines have cooperated in the past decades through mergers, alliances and codeshare agreements and consequently improved their network connectivity, including facilitating passenger journeys at every step of their air travel (single ticketing for a set of flights, seamless check-in, bag tracking, etc.). Finally, the passenger post-flight phase, including immigration control, luggage processing and again surface access from the airport to the final destinations (doors), should be considered as well [29].

Taking the above-mentioned phases into account, a door-to-door journey for an air passenger actually represents an intermodal chain consisting of the following stages: access to the airport via different surface transport modes or systems, the airport and non-airport activities at the terminal(s) before the flight, the airline flight, the activities at the airport terminal(s) after the flight and egress from the airport to the final destination via different surface transport modes or systems. Traditionally, different transport modes and systems have been considered independently, particularly in terms of the funding and transport services providers involved. Despite the fact that particular transport service providers operate in this way, passengers usually consider their journeys altogether. This implies that when planning a journey, passengers consider the costs, convenience and complexity of the entire journey instead of a particular phase [30].

4. Research Methodology

4.1. General

Moving towards multimodality, air passenger transport is a very complex process that faces many constraints (e.g., new infrastructure, new measures) and resistance (e.g., passenger behavioral change, transport operators hesitate to cooperate). By using the five-step approach presented in Figure 2, we attempt to address this problem and provide some guidelines on how to move closer to the realization of multimodality. The research in this paper is exclusively related to the European transport market.

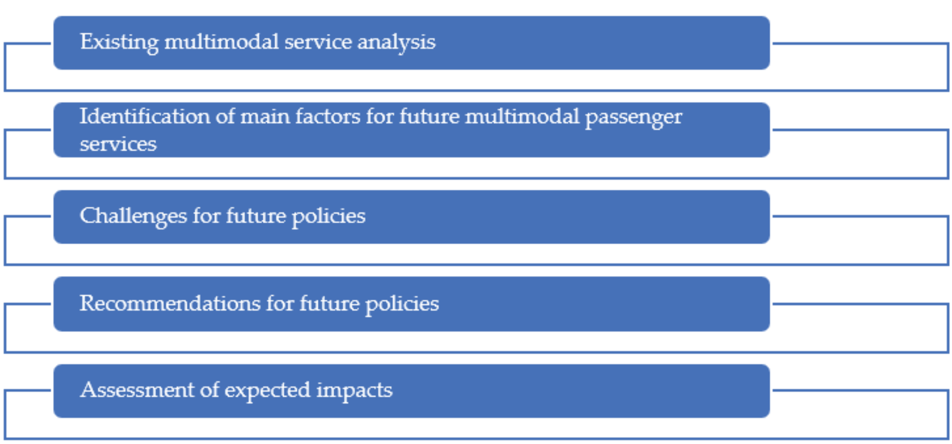

Figure 2. Five steps of the proposed research approach.

This process starts with an overview of the existing collaborations between transport operators in Europe, where at least one is from the aviation industry. An important step to understand the problem is to identify and define main factors that influence and shape the multimodal service (Figure 2). The factors are identified based on an analysis of the existing multimodal services, as well as on the basis of previous knowledge and literature related to the individual transport developments. Further, we discuss several challenges related to establishing a multimodal system and which set out the opportunities for improving the future transport system. Subsequently, a set of recommendations to overcome the presented challenges, in the form of pre-conditions that need to be met, is developed. The final step includes an assessment of the possible impacts of a multimodal system on passengers, the transport industry, the environment and policy makers.

4.2. Existing Multimodal Service Analysis

The existing examples of multimodal agreements among transport operators in Europe, of which at least one is from the air transport sector, are very limited, which are given in Table 3. The most common are the intermodal agreements between airlines and rail operators. Among these examples, one may observe two different approaches in developing this type of cooperation. The most common approach is that an airport–rail link is offered as part of a mainline rail or commuter rail service. This is a dedicated railway line that connects the main rail station in the city and the station at the airport terminal and is operated by express, intercity and commuter trains. In addition to passengers traveling to the airport, these lines are also used by passengers who continue their journey by train. The other approach is to build a rapid transit or light rail system between the airport terminal and the city center that offers a non-stop service with a high frequency. Along with air passengers, these lines are also used by employees who work in the airport area on a daily basis.

Either way, these agreements have found a level of political support in the European Union because certain environmental externalities can be reduced by transferring passengers from air transport to high-speed rail (HSR) or by lessening congestion at some European hubs that operate under capacity constraints [31].

Table 3. Existing multimodal agreements among transport operators in Europe and their characteristics.

Name	Contract Parties	Characteristics
Rail&Fly [32]	Deutsche Bahn-German Rail Company Airlines Tour operators	• Train ride from any train station to any airport in Germany; • Service can be booked only in combination with an international flight ticket; • The ticket price is reduced in comparison to when separate tickets for air and rail are bought; • For flight bookings in the economy class, train tickets are for the 2nd class, and for flights in the first class, train tickets are for the 1st class; • The ticket is valid the day before the flight departure, the day of the flight departure, the day of the flight return and the following day after the flight return;
AIRail **(Germany)** [33]	Deutsche Bahn Airlines Lufthansa, American Airl. Emirates	• The service is provided from Cologne, Stuttgart and Dusseldorf to Frankfurt airport; • The ticket has the train number and flight number of the operating airline; can be booked in the operating airline booking systems; • Check-in for the final destination is enabled at the train stations in Cologne and Stuttgart, resulting in two boarding passes, one for the train and one for the flight; • When returning, passengers will receive the boarding pass for the train at the embarkation airport; • The luggage can be checked only at the departure airport.

Table 3. *Cont.*

Name	Contract Parties	Characteristics
AIRail (Austria) [34]	Austrian Federal Railway (ÖBB) Austrian Airlines	• The service is provided from Linz and Salzburg main train stations to Vienna airport; • From Linz and Salzburg there are hourly AIRail connections; • Single ticket for the train ride and the flight; • Members of the Miles and More loyalty program earn awards and status miles on all AIRail trips.
City Airport Train (CAT) [35]	CAT Airlines-Austrian Lufthansa Eurowings Swiss Brussels Airl.	• A rapid non-stop connection between the city center and Vienna airport (travel time is 16 min); • Very important airport transfer alternative due to high punctuality rate (close to 98%); • 'City Check-In' service—a check-in hall within the CAT City Terminal with all the amenities of an international airport; the passenger receives a boarding pass and hands over flight luggage, free of charge; • Austrian ticket counter in the city terminal for rebooking or buying tickets, as well as free parking at the Wien Mitte car park.
Fly Rail Baggage Check-in [36]	Swiss Railway Zurich airport Berne airport Geneva airport	• Check-in flight luggage at 56 train stations in Switzerland and the boarding pass reception; the checked luggage receives its own IATA-Code; • At the destination, the luggage can be delivered to the specified address or the passenger can collect it from the local station; • The service is charged with fixed price for each bag.
Train + Air [37]	French National Railway (SNCF) Air France	• Available for international departures and arrivals at Charles de Gaulle and Orly airports; • Single ticket for the arrival or departure with the high-speed train (TGV) and the flight; • In case of late arrivals, it is guaranteed that the passenger will be rebooked for the next flight or train; • Members of the Flying Blue loyalty program earn miles on the train route; • Taxi transfer between Paris-Orly airport and Massy TGV train station is provided by Air France free of charge.

All of the examples mentioned above offer a number of potential advantages for the parties involved, i.e., airlines, rail operators, intermodal airports and passengers. They enjoy strong political support in Europe, in part because of the perceived contribution they can make to the achievement of environmental policy targets [38].

4.3. Identification of Main Factors Influencing Future Multimodal Passenger Service

In order to provide conditions that enable the introduction of complete multimodality in air passenger transport with air transport as the central mode, it is necessary to learn how passengers perceive the whole process and behave while making their choice of surface access mode on their way to and from the airport(s). Bearing in mind that air passengers have different preferences depending on the purpose of their journeys, it is important to gather information related to different categories and segments in order to understand their behavior.

In the following sections, the objective is to examine the key factors that influence the use of multimodal transport by passengers who travel by plane, namely air passenger segmentation, demographic and socio-economic characteristics, airport access mode choices and economic and political factors.

Air passenger segmentation: In air transport, there are two basic trip purposes: transport taken primarily for business and transport taken for a number of non-business reasons (e.g., holiday, visiting friends and relatives (VFR), education). Business travelers are time-sensitive and relatively indifferent to price, while non-business (leisure) travelers are price-sensitive and show more flexibility over travel time.

In addition to the trip purpose, air transport planners and researchers further segment the air travel market by applying different attributes. For example, the following approaches in passenger segmentation are identified: (i) the situational segmentation methodology based on grouping passengers according to booking preferences and travel requirements; (ii) the socio-economic segmentation approach based on personal and social characteristics, such as gender, nationality, religion, age, physical (dis)abilities (which may require special assistance, such as use of wheelchairs), relationship status, income, first language, occupation and education or qualifications, as well as whether passengers are traveling alone, in a social group, in a family group or with babies or young children; (iii) the psychographic segmentation approach based on criteria such as personal values, behavior and attitudes (trip motivation, destination, length of flight, length of total time away from home, travel class, cultural background of the passenger, airline preference, membership in an airline or alliance loyalty programme and environmental considerations) [39].

Passenger segmentation is the subject of many studies, and the two main groups, business and leisure, have been thoroughly examined, along with the various sub-segments in each of these two major groups. However, the sustainable development of air transport requires air services to be continually adapted and for new ones to be offered in order to serve more markets. In order to be viable, such services must be acceptable to air passengers, meaning the sustainable development of air transport depends on the willingness of passengers to use these new transport services.

Demographic and socio-economic characteristics and attitudes: Demographic and socio-economic characteristics have been proven to be critical determinants of transport mode choices, the most important of which that can be singled out are gender, household members, income and car ownership. Overall, younger people (the age group of 16–19) and older people (55+) are less likely to fly than middle-aged passengers. In terms of socio-economic groupings, the largest groups of infrequent flyers are junior managerial or skilled manual workers, with more frequent flyers than infrequent flyers within then middle and senior managerial staff groups [40]. Gender has been studied with regard to travel purposes, and it was found that men tend to travel more often than women for business, but women travel more often for leisure purposes. Gender differences in the peak age for travel only exist in business travel, with travel for women tending to peak earlier than travel for men [41].

Generally, in order to travel, passengers need to perceive traveling as safe, to have the confidence to travel and there need to be favorable economic conditions [42]. In air transport, the choices are reduced to choosing the airport, airline and transport mode to and from the airport. The purpose of air travel (e.g., business travel vs. non-business travel) has been proven to be a major factor when choosing among available airports [43,44]. With regard to airline choice, the fare is another decisive factor affecting the choice, whereby business passengers are willing to pay more for a shorter travel time than non-business passengers [44].

Airport access mode choice: Since the airport itself is not the primary destination, consideration must be given to access to the airport via different transport modes and systems. At most large airports, the surface access is provided by the road and rail transport modes. The former include cars, taxis and buses. Those of the latter include light rail transit (LRT), subway and metro systems, regional and national conventional rail and HSR systems, the Transrapid Maglev (TRM) system and the recent, futuristic hyperloop (HL) system. All of the abovementioned modes and their systems usually operate either through cooperation or competition. At smaller regional airports, the road-based transport mode is most frequently the airport surface access mode, i.e., cars, taxis and buses [45].

Factors influencing the choice of airport surface access mode are availability, access time, access cost, transport service frequency, reliability, resilience (resilience is commonly used to describe the ability of an entity or system to bounce back to a normal condition after its original state has been affected by a disruptive event [46]), punctuality, convenience of the arrival time at the airport, convenience of storing and retrieving luggage and whether the access involves transfers [30,47,48]. The access time and cost are directly proportional to the airport access distance for almost all access modes and systems across many European and US airports [45]. Among all options (e.g., car, taxi and public transport), car transport usually has the largest share due to the greater comfort, convenience, personal security and reliability perceived by passengers [49]. Thus, to become attractive alternatives, taxi and public transport options should meet passengers' needs and preferences by understanding the main factors that influence their choices.

Along these lines, access cost and travel times to and from the airport are considered the two most significant parameters that negatively affect the access mode choice regarding alternative-specific attributes [27,50]. Reliability is the next most important factor for air passengers, because late arrivals at the airport cause high amounts of stress due to the high possibility of missing a flight [51]. Some studies have shown that price is less important than time if a new, more reliable public transport system is available to access the airport [52].

Economic factors: The economic development of a region will impact both the amount of investment that may be made in the local transport system, as well as the travel behavior patterns of its residents and visitors [15]. Moreover, the economic characteristics of the population area that is served must be taken into consideration when allocating transport resources to allow for factors such as access to a private vehicle, working hours or other travel patterns, availability of funds for public transport fares, familiarity with the local transport network and other characteristics that may reflect the overall economic status of the prioritized area [53].

Many efforts have been undertaken to reduce market entry barriers and enhance competition; hence, the level of development in terms of fair competition varies across Europe. The process unfolds very slowly because the EU states are still protecting their companies, meaning there is a mixture of different national transport systems and not a single transport market.

Political factors: The multimodal transport concept does not operate in isolation; the multimodality is part of a large integrated transport system. For multimodality to be successful, policy makers at all levels (municipal, regional and national) must consider transport as a whole, not in unimodal segments. Therefore, to ensure maximum connectivity in multimodal transport, there must be no regulatory bottlenecks. Some of the regulatory bottlenecks can result from some other policy objectives, and these can have direct effects (e.g., safety and quality inspections and security measures) and indirect effects (e.g., cabotage restrictions such as restrictions on domestic transport) [54].

Legal diversity is often an obstacle to commercial operations between partners from different legal systems, i.e., different countries. Laws and regulations should be made compatible, promoting the free interchange of passengers from one mode to another.

5. Prospective and Future Developments

5.1. Challenges for Policies

The key challenges the transport industry will face in developing a multimodal service are primarily focused on how to create an attractive and efficient multimodal network. This section analyzes the main challenges, as they should provide valuable insight for future guidelines when building the corresponding transport policies.

Four hour door-to-door travel: The challenge of providing 4 h door-to-door travel within the EU (the goal set by Flightpath 2050 [55]) can be considered as an initial step towards multimodality in the given context. The concept of 4 h door-to-door journey time within the EU [13,56] is presented in Figure 3.

Here, t_{ga} is the surface access travel time from the origin to the departing airport; t_{pre} is the time that the passenger spends at the airport before boarding the flight (passport control, security control, waiting time and non-aviation activities, boarding time); t_{air} is the time spent on the flight; t_{post} is the time that the passenger spends at the airport after arriving (passport control, waiting time in the luggage claim, custom control); t_{eg} is the surface travel time from the arriving airport to the final destination.

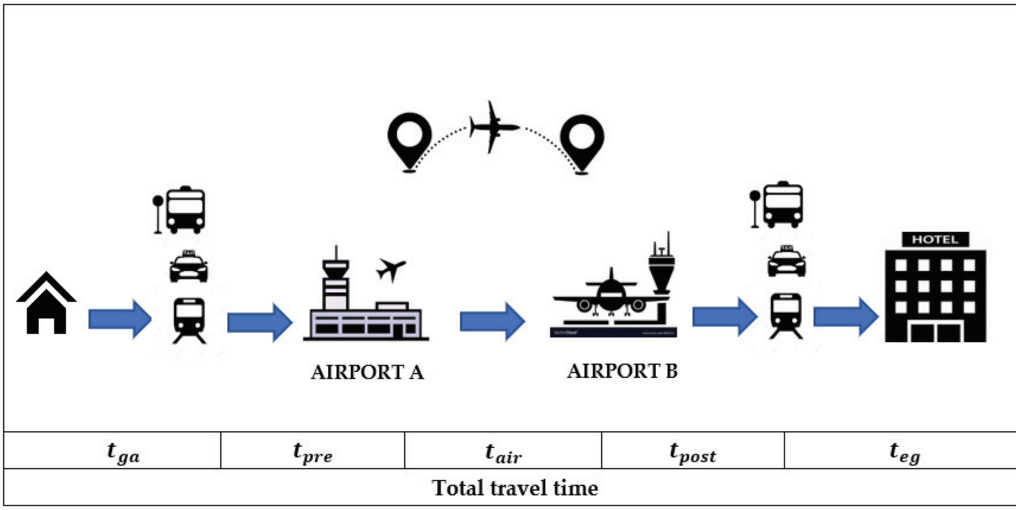

Figure 3. Door-to-door passenger travel time.

The 4 h door-to-door travel time via different airport surface access modes and their systems within the EU is difficult to achieve due to the time requirements for all parts of the travel chain [57]. Theoretically, 90% of trips involving **at least one flight segment** and airport access and egress **only by car** could be completed door-to-door within 4 h within and between the EU-28 member states [58].

Single ticket and payment system: Price integration across all transport modes has not been a common practice for transport authorities across the region and beyond, but it will make the multimodal system easier and facilitate transfers [59]. When purchasing a single ticket, the system should automatically calculate different price combinations from the beginning of the journey to the destination, allowing the passenger to choose the most suitable one. The revenue should be split between the transport operators based on the transport means the passenger traveled with.

However, a prerequisite for a multimodal single ticket and payment system is free access to price data from the transport operators involved. At present, there are no common EU rules on access to fare data (beyond the Delegated Regulation 1926/2017 on EU multimodal travel information services). This means that data are collected and made available in different formats only based on common standards developed by the parties of the commercial agreement [59]. The evident lack of interoperability between the application programming interfaces (APIs) of various stakeholders and the application of different standards, which additionally increase costs and discourage investment, is a technical challenge that has delayed the development of this system [59].

Synchronization of timetables: Another problem is working out how to synchronize timetables from different transport operators at intermediate points, such as railway stations, bus terminals or airports, in order to maximize the number of synchronized train or bus arrivals at transfer nodes (e.g., airports) or to minimize the total transfer waiting times experienced by passengers. Most of the European airports are very busy hubs where departure and arrival times are strictly given without the possibility of change. However, due to the large number of train and bus arrivals and departures per hour, it is not possible and not even necessary to make interconnections between all flights from a particular airport and arrivals and departures of other public transport modes individually. For small, secondary airports, which are not congested, timetable synchronization is much easier.

The most important criteria from the passengers' perspective related to timetables are synchronization at interchange nodes, operational reliability, information availability and supplementary services [60]. There are many different approaches and criteria leading to solutions for the timetable synchronization problem available in the literature [61]. Based on the overview of the proposed solutions, it can be concluded that there is not only one approach and one universal solution to this problem. Individualized solutions are necessary for each specific situation.

Luggage integration: The transport of luggage is one of the decision-making factors involved in the choice of transport mode. Despite the increasing costs and increasing traffic problems, the car is still the most popular means when accessing the airport, above all due to luggage handling. The reason is that compared to all other flexibility aspects, flexibility with luggage is highly valued [62]. Thus, the public transport must be highly attractive and should operate within the framework of an overall airport feeder system.

Around 130 airports worldwide have rail connections [38], with further railway connections being planned. However, there are only a few airport rail operators that offer an in-town check-in service for passengers to drop off their luggage before the flight at the central railway station (some examples can be found in Table 3).

Data sharing: Towards ensuring reliable and efficient operations, as well as accurate passenger information, many public transport systems today rely on digital information systems. However, transport operators appear to be more reluctant to share their data for the fear of it being misused [59]. Some of the data might not be suitable for sharing due to privacy, competition laws or commercial restrictions and concerns.

In order to create a multimodal ecosystem and to exploit the full benefits of digitalization, access to high-quality data, including data on routes, schedules, fleet availability, accessibility information, road works, traffic and disruptions, will have to be ensured [63]. This problem is further deepened by the fact that no common EU rules or standards for access to fare data exist (beyond the 2017 Delegated Regulation) [59]. This is the reason why data are still being collected and made available in different formats.

Revenue sharing: The most important concern of the stakeholders involved in multimodal transport is the matter of ticket revenue sharing. Public service obligations (PSOs), in particular, were highlighted as an obstacle for revenue sharing in integrated ticketing [59]. The integration of public (usually subsidized) transport services and commercially viable services can be difficult, because the subsidization of operations can serve to determine how transport operators can sell their tickets. PSO operators may be exempted from providing access to price data under clauses related to the subsidized prices [59]. This is why revenue sharing between multiple parties in a multimodal service system requires new models for price and revenue collections. A government body may be responsible for setting rules for cost and revenue sharing and for settling all transactions.

Responsibility sharing: When the transport service is provided by more than one transport operator and involves different transport modes, the rules of responsibility and the laws related to these operators are important points. The main question in terms of passenger rights and responsibilities is: When a journey is disrupted (e.g., in the case of a delays, cancellations, lost luggage and injury or death to passengers), who is responsible?

In the current system, if a journey is conducted by different transport operators, passengers may not be fully protected throughout their journey, because the existing passenger rights legislation may be applied independently to each individual transport mode [64]. In other words, passenger rights cannot be guaranteed when a disruption occurring during one transport segment affects the following one if the latter segment is operated via another mode of transport.

The existing multimodal services are generally based on cooperation agreements between an airline and a high-speed rail operator (Table 3). General terms and conditions regarding multimodal services offered by these transport companies do not seem to include any specific provisions addressing the issues of passenger rights in a multimodal context [64].

Thus, in the case of multimodal transport services that are sold under a single contract of carriage, it is very important to implement new measures (recommendations, rules, laws, etc.) that will provide a proper balance between protecting the passenger rights, on the one hand, and profit for the transport operators, on the other hand.

5.2. Recommendations for Policies

The conditions that made seamless door-to-door journeys in the European Union (EU) possible include technological progress, big data usage, strengthening of the EU and the synergistic attitudes of countries and companies [4]. The purpose of this section is to present recommendations concisely within the context of the development of a multimodal system.

Future air passenger segmentation: For door-to-door air passenger journeys, particular attention should be given to the following two segments: (a) empowered travelers who control their own trips, independently access the information, plan and reserve certain parts of the trip independently, react to plans and adapt them to the circumstances; (b) guided travelers who entrust most of their planning and delivery to agents and rely on them to possibly adjust the itinerary to new circumstances [65]. Six profiles of future air passengers have been identified (for the year 2035), reflecting major developments in the European transport market, as shown in Figure 4 [66].

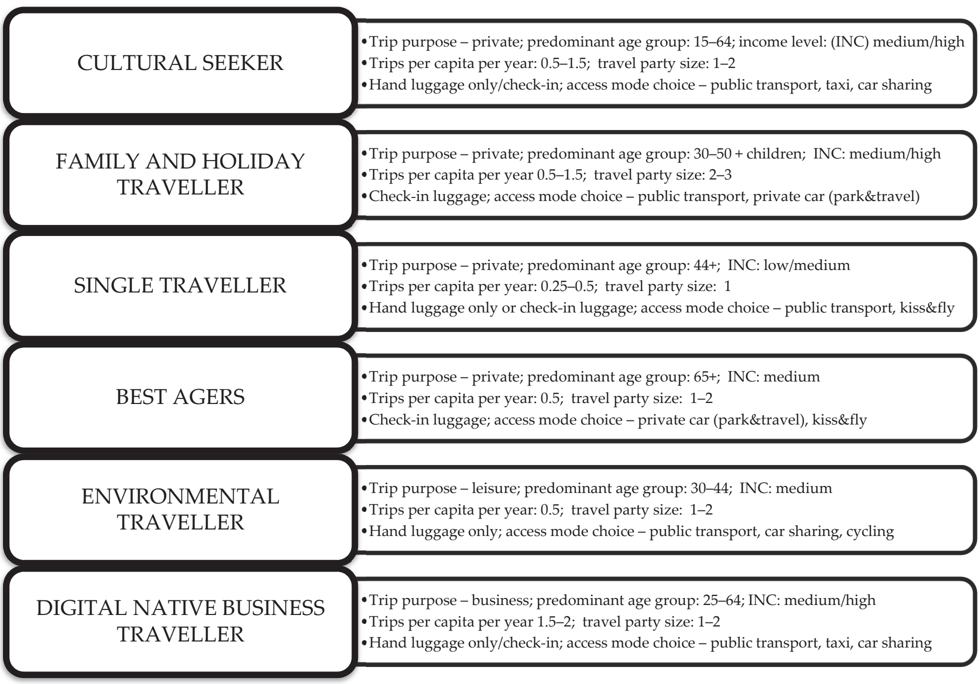

Figure 4. Future passenger profile identified in DATASET 2050 (data are taken from [66]).

What is certain is that the price will remain the main driver behind the customer's choice. Additionally, it can be expected that business travelers will still value their time above all. However, people are becoming increasingly concerned about the environment, which will further influence their travel choices. For one segment of passengers, simply traveling by air will not be enough and they will be looking for something extra. Some operators will pay special attention to adolescents and offer them special sections on their larger aircrafts for meetings, playing games and establishing friendships with people of their own age. The number of passengers from developing countries using air transport services for the first time is also expected to increase [67].

It is expected that the COVID-19 pandemic will influence the market segmentation in the airline industry [68] and in other modes of transport as well, so it is important to understand how air passenger traffic will evolve in the short term during the industry restart. Moreover, future market research efforts may indicate new segments based on passengers' attitude to travel due to the pandemic or other external global disruptions.

Harmonization of legal frameworks for multimodal transport operations: There has been an effort made to harmonize certain rules for door-to-door transport operations involving several modes of transport where the origin and destination are not in the same country. Directive 2010/40/EU7 provided the legal framework for the development of intelligent transport systems (ITS) and effective information systems and for the collection of traffic data throughout all modes of transport; however, the passengers' rights legislation remains mode-specific. In 2015, the European Parliament called in a resolution for a proposal covering multimodal journeys with clear and transparent protection of passengers' rights in the multimodal context, taking into account the specific characteristics of each transport mode and integrated multimodal ticketing.

As far as multimodal transport is concerned, there is no international treaty that covers transport operations involving more than one mode of transport that is in force and implemented. The starting points for developing these types of rules could be the existing agreements on the combined or intermodal transport of goods: (1) the European Agreement on Important International Combined Transport Lines and Related Installations (AGTC) and (2) the Agreement on Organizational and Operational Aspects of Combined Transportation between Europe and Asia. The AGTC defines a common infrastructure quality standard for combined transport in the main European transport corridors. It contains an annex that lists all of the lines and corridors to which this minimum standard will apply. The annex is updated regularly in light of information received from the participating states [69].

Four hour door-to-door journey: The Flightpath 2050 goal is to enable a door-to-door travel time of four hours or less for 90% of all intra-European travelers. Achieving this goal will require multimodal and procedural improvements to create a favorable operational environment that supports time-efficient and affordable travel. Generally, transfers from one mode to another have a negative effect on the overall travel satisfaction [70]. Thus, the satisfaction with trips with a large number of legs, such as metro, train and air trips, is expected to depend on the transfer experience. Thus, the overall passenger satisfaction can be improved by reducing these travel critical phases; however, this will not suffice. Reductions in airport access time must also be achieved, which will be made possible by upgrading airports into real multimodal transport nodes.

In general, the 4 h door-to-door journey time goal in Europe could be possible under the following conditions:

- Short-haul non-stop flights must be taken (flight duration should be approximately 1 h);
- The smooth movement of passengers and their luggage through the terminal must be ensured;
- An appropriate airport ground access system at origin and destination airports should be provided, along with high-quality infrastructure. Travel times will vary depending on the timetable (departure and arrival times), as well as the time of the day when the journey is taken (peak or off-peak);
- The location of origin and the final destination within the catchment area should be accessible within a determined time (no more than 45 min). Each airport has a catchment area, so the travel times to and from the airport will depend on the place where the journey begins and ends.

Single ticketing and payment system: For multimodal ticketing and payment systems, it is essential that the data are shared among transport operators and transport modes, because transport can be coordinated only if these are fed with quality data generated by the different transport systems [59]. The computerized reservation systems (CRS) used in the airline industry can be used as an example of good practice. This system is used for booking and scheduling information by travel agents on behalf of airlines, but it also provides information on hotels, car rental services and other activities. For this purpose, data sharing regulations were imposed on airlines both in the US and in the EU to force transparency and neutrality in the display of information via these platforms [59].

Another good example is the Finnish Act on Transport Services, which sets out three obligations to open up APIs. It mandates access to essential data concerning mobility services, the granting of access to a sales interface for single tickets or a reservation interface for transport and access to a sales interface when acting on someone else's behalf [59]. This act mandates that public service providers operating under a PSO comply with interoperability requirements. In addition, the relevant provisions of Regulation EC 1370/2007 on revenue allocation between the contracting authority and the transport operator provide the legal basis for appropriate interventions [59].

Synchronization of timetables: Timetable synchronization is a very complex problem affected by numerous other conditions and factors. The most important one is the transfer time between two modes of transport (i.e., arrival time of the vehicle from one mode and the corresponding departure time of the vehicle for the other mode). Transfer times that are too long can cause passengers to have to wait, meaning the attractiveness of this service will be low, while those that are too short can decrease the level of comfort and increase the stress caused by the fear of missing connections [71]. Another important factor is the demand distribution over time, due to the high demand variability.

Although it is very hard to propose a single solution in terms of timetable synchronization, some recommendations can be highlighted [71]:

- Shorter transfer times can be applied to those connections with predominantly business passengers because they travel frequently, alone, with less luggage and know the process very well;
- Longer transfer times can be applied to those connections with leisure passengers because they carry more pieces of luggage, usually travel in a group and often search for additional information;
- In order to cope with demand variations, time should be divided according to the transport extent (e.g., according to the day—working day, weekend—or according to the time of day—peak, off-peak, morning, evening, etc.) and the process should be optimized according to each individually considered time period with different operational features.

Luggage integration: There is great interest among air passengers in using the train for arrival to the airport if a luggage check-in system at the train station is offered [62]. This will certainly encourage a modal shift of the intra-European short-haul air-feeder traffic, as well as the airport-feeder traffic overall to the train.

Data sharing: In order for seamless multimodal transport to be achieved, mobility platforms are needed, although these require access to data. Moreover, data sharing among transport operators is also necessary because in this way it will be easier to coordinate their services [63]. However, data sharing regulations play an essential role in supporting sustainable mobility. An example of a data sharing policy framework is based on good practices from the existing policies and data sharing initiatives and consists of five interdependent and complementary layers [72]:

- *Use and analysis*: Policies to enable public, private or other third parties to access shared data and to ensure the ethical use of data to protect public interests.
- *Governance and accountability*: Policies that establish roles and rights of parties over their data and shape the structure of the governing bodies.
- *Data infrastructure*: Policies related to the development of physical and digital infrastructure to allow management over data resources and flows of data.
- *Data standards*: Policies to support the development and adoption of data and metadata standards to ensure interoperability across multiple stakeholders.
- *Data collection and merging*: Policies to enable the collection of data generated from diverse sources and the assembly of data sources within a data sharing initiative.

Big data opportunities: Digital transformations and the associated utilization of big data technologies (mobile phones, Twitter, credit cards, Google data, FlightRadar24 data, etc.) have created good opportunities by allowing the collection of unprecedented volumes of data across all modes and transport systems. In terms of door-to-door passenger journeys, the information that can be collected relates to the passenger profile, residence or accommodation at the destination, time of stay at the destination, places visited, frequency of trips, another factors. In the kerb-to-gate and gate-to-kerb terms, the obtained data could be used to identify and predict bottlenecks and to collect real-time information about airport services [73]. Information from personal mobile devices combined with information available from different stakeholders and infrastructure and vehicles could be used for short-term predictions of passenger flow, for strategy development and in case of disruptions [17].

Multimodal terminal transfer distance, speed and time: A multimodal passenger terminal has to ensure the efficient and safe transfer of passengers between road, rail and air transport modes. This is the point at which several modes of transport are physically and operationally integrated (a user-friendly walking environment between stations), which complement each other to facilitate the passenger's journey from origin to destination. In a multimodal system, airports are seen as the main multimodal terminals. Although building a new multimodal terminal has its advantages, this is a very time-consuming and costly option, especially within Europe. Another option is to adapt the existing airports to the requirements of this specific service by implementing new multimodal transport options.

A multimodal terminal should provide the following:

- Suitable local accessibility to the site for all users (especially the disabled);
- Platforms for passengers to arrive or leave the terminal;
- Direct access between different platforms for all modes of the terminal (rental car facilities, offsite parking, public transport and airport);
- Adequate facilities facilitating transfers between modes;
- Reduced travel and waiting times compared to the time needed for the same journey without a transfer;
- A common area to wait for transfers, where passengers can do other activities;
- Timetables and information desks for the different modes located all over the terminal.

Attractiveness: Attractive service features tailored to air passengers are essential for the acceptance of public transport. Most European cities have well-developed public transport networks, although the problem is that these networks work mostly independently from one another. This reduces the overall attractiveness of public transport in comparison to private cars.

To attract users, public transport must offer services that are fast, reliable and performed at high frequency. Additionally, public transport is expected to be safe and operated to high environmental standards. By making public transport seamless, more people could shift from using private cars to public transport for trips to the airport, which will in turn lead to less congestion, lower air and noise pollution and greater safety.

A successful multimodal transport system will require that passengers are provided with practical and reliable information about their journey in real time, such as potential changes, connection times, alternative routes and alternative transport options. Offering affordable tickets, ticket discounts and special services is also a way to quickly attract potential passengers.

Other requirements will be to facilitate market access and to protect fair competition by discouraging discriminatory practices. These will need to be accompanied by adequate enforcement measures.

Some other attributes that can attract people towards using public transport, i.e., the future multimodal service, are [63]:

- Simplifying the ticketing system with a user-friendly interface and customized and transparent reporting, along with multiple ticketing choices and ways to buy tickets;
- Facilitating seamless connections at all stages of the journey (providing better interchange facilities) and providing interoperable systems among transport modes;

- Increasing the system resilience, which will be of particular importance in multimodal systems, which tend to be more sensitive than individual transport systems because they consist of more than one mode of transport.

Multimodal alternatives: There are three business models operated under a single contract that can be implemented for multimodal transport:

1. A single contract resulting from an agreement between two or several operators to offer a multimodal product, in which one of the operators acts as the single contracting party towards the passenger. In such case, provisions regarding liability sharing are included in the agreement between the operators involved, e.g., Maas;
2. A single contract consisting of a product offered by an intermediate entity (such as an online seller or a tour operator, for instance), which includes transport services from all operators involved. The passenger enter a transport contract with the intermediate entity, e.g., charter airlines;
3. A single multimodal transport operator that has a fleet of vehicles (e.g., aircraft, trains, buses) at its disposal, either through direct ownership or under lease, and that offers the multimodal service as a single entity and has its own insurance coverage arrangements, since it will be accepting liability for the entire transport process, e.g., cargo integrators.

5.3. Assessment of Expected Impacts

In this paper, we address the potential impacts that the multimodal concept is expected to have on passengers, transport operators, the environment and policy makers.

The multimodal service is expected to have a positive impact on passengers in terms of providing better connectivity. The expansion of a transport network as a result of multimodal connectivity should bring about better links to regional and urban areas, which in turn should increase tourism, the city's attractiveness and the citizens' well-being. It is also expected that passengers will have access to an improved transport service with better legal protection if a disruption occurs during a multimodal journey [64]. In particular, this type of service should have positive impacts for people with disabilities as it will provide them with access to multimodal transport systems and services tailored to their specific needs [46]. In order to succeed in the market, this modal integration has to allow generalized cost reductions for some journeys [31].

Transport operators should benefit from the increased demand due to the improved connectivity and interchange opportunities, as well as the decreased congestion and better legal protection of passengers. By providing services from remote cities to airport hubs, surface modes can increase air passenger demand to their major market [6]. A multimodal service can help in linking different businesses and markets, which in turn should lead to improved operating efficiency and profitability.

Regulators and policy makers nowadays are constantly searching for transport solutions that will reduce congestion, pollution and energy consumption and increase safety. It is believed that such services will protect the environment by promoting transport modes that are more sustainable, i.e., by ensuring an optimal modal combination (a shift from the use of private cars to public transport) [8]. However, this will require the use of new communication and information technologies in order to provide passengers and transport operators with real-time data, to build new infrastructure to facilitate seamless transport and to adopt new policy measures specific to multimodal journeys (legislation).

6. Conclusions

A multimodal air passenger transport system is envisaged for Europe to optimize the comparative advantages of each transport mode involved to achieve more sustainable transport within and between countries. In order to provide seamless multimodal services, it is necessary to connect individual transport operators through efficient transport infrastructure and services at the national and international levels.

This paper proposes a systematic approach and recommendations based on an analysis of the main factors and challenges in developing a multimodal air passenger transport system and services.

These main factors include air passenger market segmentation, demographic and socio-economic characteristics, airport accessibility, economic conditions and political circumstances.

The main challenges in developing a functional multimodal air passenger transport system in Europe enabling 4 h door-to-door journeys within the EU include a single ticketing system, timetable synchronization and luggage integration, as well as data, revenue and responsibility sharing.

The recommended possible future actions to be undertaken in order to face the above-mentioned challenges and forthcoming trends for air transport system development are summarized as follows:

- Air passenger market segments must evolve due to the influence of digitalization and the increased use of new information technologies, along with changes in environmental and political awareness, which should be taken into account;
- The rules must be harmonized to cover the relationships between the operators of the different modes of transport involved, both nationally and internationally;
- New policy and legislative measures specific to multimodal journeys and related to data, revenue and responsibility sharing need to be adopted; special attention should be paid to the regulation of data sharing, since data sharing is the first step towards an integrated ticketing and payment system;
- New communication and information technologies should be employed in order to provide passengers and transport operators with real-time data;
- A remote luggage check-in system should be offered;
- Seamless connections should be facilitated at all stages of the journey (via better interchange facilities and timetable synchronization) to ensure the acceptance of public transport as a transport mode.

The ways in which individual transport modes and the environment interact can give rise to economic benefits, whereby the impacts of the multimodal service as a whole will be greater than when each service operates individually. However, the impacts of each transport mode and the overall multimodal performance will vary across the markets. The success will depend on transport infrastructure developments, access to facilities, passenger attitudes and behavior and economic factors. Therefore, an appropriate strategy should be developed for each market, setting the main priorities that cover all modes of transport and striving to achieve a fair and efficient single market. After this, the priorities for each individual transport mode should be addressed.

Regardless of the prevailing circumstances, these recommendations are fundamental to allow the multimodal service to operate optimally while reducing congestion and emissions. It is expected that private and public transport operators, as well as governments, could use these results as guidelines for a feasibility study of multimodal transport.

Further research on the topic of air passenger multimodality systems could be performed as follows:

- A thorough impact assessment of the participants in future systems;
- Strategy and scenario planning and studies on data usage and passenger rights in a multimodal operation environment;
- Evaluations of the already established and conceptual systems;
- Examinations of the willingness of transport operators and passengers to use fully integrated multimodal air passenger transport systems through interviews or surveys.

Author Contributions: Conceptualization, S.D. and D.B.; methodology, M.K., K.K. and M.J.; resources and information providing, D.B., S.D., M.K., K.K. and M.J.; writing—original draft preparation, D.B.; writing—review and editing, S.D., M.K., K.K. and M.J.; visualization, M.K.; supervision, M.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by SESAR Joint Undertaking, within the project "Synergies between Transport Modes and Air Transportation" (SYN+AIR) under grant number 894116.

Acknowledgments: Parts of this study has been supported by SESAR Joint Undertaking within the project "Synergies between Transport Modes and Air Transportation" (SYN + AIR) under grant agreement no. 894116 and the Ministry of Education, Science and Technological Development, Republic of Serbia, as part of projects TR36033 and TR36002 (2011–2022).

Conflicts of Interest: The authors declare no conflict of interest.

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Airport Access Mode Choice: Analysis of Passengers' Behavior in European Countries

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Citation: Colovic, A.; Pilone, S.G.; Kukić, K.; Kalić, M.; Dožić, S.; Babić, D.; Ottomanelli, M. Airport Access Mode Choice: Analysis of Passengers' Behavior in European Countries. *Sustainability* **2022**, *14*, 9267. https://doi.org/10.3390/su14159267

Academic Editors: Vittorio Di Vito, Gabriella Duca and Raffaella Russo

Received: 21 June 2022
Accepted: 26 July 2022
Published: 28 July 2022

Abstract: Transportation systems require many challenges in providing seamless door-to-door mobility. The main initiatives are encouraging a shift from private to other transport modes by providing a fully integrated multimodal service in which the coordination and data sharing among different stakeholders are required. The idea of this paper is to analyze the mode choice, as well as the variables that affect the travelers' airport access mode choice. For that purpose, we used multinomial logistics (MNL) regression to determine probability of mode choice given various multimodal chain alternatives. The inputs of the proposed model were based on the answers from the participants of the online survey which was disseminated in Europe. Through more than 2000 answers to the survey, we collected the data related to the factors that influence the airport access mode choice, travelers' attitude, motives for traveling, as well as the socio-demographics of participants. Afterwards, we investigated the influence of the main factors that have an impact on the non-coordination in the multimodal travel chain. The obtained results highlight the impact of the factors "reliability" and "waiting time" in making mode choice.

Keywords: mode choice behavior; multinomial logistics regression; correlation analysis; seamless D2D travel; coordinated multimodal service

1. Introduction

Transport systems are facing many challenges in providing efficient mobility solutions regarding both users' and transport authorities' perspectives. There are numerous local initiatives of policymakers in mitigating the issue (i.e., traffic congestions, noise, and pollutions) which is mainly caused by the widespread use of private cars (see [1]). The problem with congestions on roads, to and from the airports, is also part of the challenge, with more people using air transport each year. A multimodal passenger transport system that includes air transport is one of the concepts towards the sustainable practice which should result in more use of public transport (PT) systems, and further, in reduction of pollution and alleviation of road congestion [2].

The idea of this paper is to investigate the opportunities and the aspects to be managed for providing seamless door-to-door (D2D) multimodal trips that consist of several transport modes, with the air transport mode as the main leg in the multimodal chain. Specifically, the seamless D2D multimodal trip should provide the coordinated trip and service to the travelers, from origin to destination, by including several transport modes (bus, train/metro, car, taxi) for arriving to the airport, as well as for departing from the airport to the final destination. The introduction of such a multimodal service requires many aspects to be managed, e.g., integrating airport access into city planning, the shift from private to other transport modes, etc. Most airports have more than one ground option that provides access to/from the airport for people. Thus, when making mode choice decisions, passengers are affected by many factors, particularly journey time, cost, travel time reliability, etc. [3]. Travel time reliability proved to be an important attribute of the transport system for passengers because of the potential risk of the late arrival and missing the flight [4]. Moreover, differences in mode choice airport accessibility are partly explained by demographic differences, e.g., age, education, etc. [5,6].

Supporting this concept, we analyzed several aspects for creating multimodal trip service considering passenger behavior and mode choice when traveling to and from the airport, as well as the impact of the non-coordination in multimodal trip. For that purpose, we designed and disseminated, in different European countries, a survey related to the transport mode choice, travel habits vs. travel purpose, frequency, factors influencing mode choice of the trips, as well as socio-demographic characteristics. After collecting the answers from the survey (this survey was conducted online due to world pandemic of COVID-19, for the purpose of the SYN+AIR project (894116) from the H2020-SESAR-2019-2 call. Respondents were mostly from Greece, Italy, Spain and Serbia (where project partners originated from), as well as from the other countries in Europe), firstly, we analyzed travelers' habits and the opportunities for creating integrated multimodal transport. For that purpose, we provided correlation analysis, in which we were able to determine the explanatory variables that affect the travelers' airport access mode choice (e.g., travel cost, travel time, reliability, waiting time, etc.). Secondly, to determine the influence of the mode choice question, and to assess the behavior of travelers in choosing the multimodal travel alternative, we performed the multinomial logistics (MNL) regression based on three proposed scenarios [7].

Therefore, the main questions that arise are: (i) If "train", "taxi (or ridesharing services like Uber of Lyft)", "metro", "combination of modes (bus or train)", "car (someone drops me off/pick me up)", "car (park at/near the airport)", and "bus" modes are available, which one is the most commonly chosen to travel to/from the airport? (ii) What are the factors that affect transport airport access mode choice? Furthermore, we analyzed the influence of the factor "reliability" and "waiting time", as well as the impact of non-coordination in the multimodal travel chain.

This research aims to conduct and update the results of previous studies on airport accessibility at the European level. It provides valuable information about the available transport services and their use at many airports in Europe. Moreover, the survey data reveal a different situation in some countries in terms of transport infrastructure, as well as different passenger's perception of factors that influence mode choice (cost, travel time, waiting time, reliability, security, etc.). All the obtained data helped in exploring existing ground access behavior and factors that may encourage PT use and decrease use of private cars and taxi, as well as providing some insights on demographic characteristics of passengers ready to change their attitude towards PT.

The result of the study differs from the existing literature in providing comprehensive statistical analysis that covers transport systems in terms of mode characteristics. Furthermore, according to our knowledge, there is a lack of studies that are based on large surveys. In this paper, we provided the results based on the survey conducted in different countries with 2199 responses and 25 questions related to motives, preferences, and travel behaviors, as well as sociodemographic profile. In addition, we proposed a method to handle answers given on Likert scale to be used in statistical analysis.

The structure of the paper is organized as follows. In the Section 2, we provide the literature review related to the airport access mode choice. The Section 3 is dedicated to data and methodology, while the results are provided in the Section 4. In the Section 5, the impact of the non-coordination in multimodal trip is discussed, while the Section 6 is dedicated to the conclusion and further developments.

2. Literature Review

At most large airports in Europe, the landside access modes and systems are based on the road and railway transport modes, such as cars, taxis, buses, subway/metro, regional/national conventional, and HSR (high-speed rail). The influencing factors for airport access mode choice are availability, access time, access cost, transport service frequency, reliability, punctuality, convenience of the arrival time at the airport, existence of transfer, and convenience of handling luggage. The access time and price have been approximately linearly correlated with the airport access distance at almost all land-side access modes and their systems across many European and US airports [8]. Air travelers' access mode choice models are based on individual characteristics (gender, age, car ownership, income, etc.) and alternative specific attributes. In order to understand airport accessibility, researchers take into account trip purpose (business or leisure air trip), so-lo/group journey, the size of passenger group, number of baggage items, etc.

A brief overview of selected papers on mode choice (published in last 15 years) is presented in Table 1. It points out the case study, model used, and main findings of the research.

Table 1. Some selected papers on airport access mode choice.

Reference	Case Study	Model Used	Main Findings—Results
[9]	Hong Kong International Airport (HKIA)	Multinomial logit model	Ground access market was shared between buses and Airport Express Railway (AE). The main reason for bus choice was low travel cost, and for AE high travel time reliability. If the travel time reliability of buses would improve, a significant proportion of departing air passengers would switch to buses.
[10]	Taoyuan International Airport in Taiwan	Mixed logit model	Out of-vehicle and in-vehicle travel times are two dominant factors that affect outbound air travelers' choice of airport access modes. Time-savings, no transfers and convenience of storing and retrieving luggage are important.
[11]	King Khaled International Airport, Saudi Arabia	Binary logit model	Determinants of airport access mode choice: income, luggage, travel time, and nationality. More travellers used private cars than any other airport access mode.
[12]	Port Columbus International Airport, Columbus, OH, USA	Binary logit models	The most important factor to consider alternative modes was reliability, followed by travel time to the airport, and flexibility of departure time for both business and non-business travelers.
[5]	Gimpo Airport and Daegu Airport, Korea	Descriptive analyses Regression model	The choice of airport access mode is significantly affected by travel time, travel distance, trip purpose, age, gender, occupation, and income. Demographic characteristics affect access mode choice for non-business more than for business travel.
[13]	Imam Khomeini International Airport (IKIA), Iran	Latent class hybrid choice models	The individuals who display neuroticism were more likely than the others to be concerned about carrying heavy luggage and about weather conditions when using public transport. Conscientious individuals likely paid more attention to travel cost than to any other attribute of public transport.
[14]	Ataturk International Airport (IST), Istanbul, Turkey	Multinomial logit (MNL)	Significant factors and variables included the trip distance to access IST, type of destination, trip cost to IST, car ownership status, employment status, travelling group size, location of the trip origin with respect to public transit influence, and time difference between the flight time and departure time to IST.

Table 1. *Cont.*

Reference	Case Study	Model Used	Main Findings—Results
[15]	Hamad International Airport (HIA), Doha, Qatar	Binary logit (current) and multinomial logit model (future)	The models results showed that current and future access mode choice is significantly affected by the trip and socioeconomic characteristics of the HIA users.
[16]	Milan-Bergamo airport, Italy	Mixed logit model	Low-cost air passengers are not low-cost customers regarding the access mode choice. Business passengers are willing to pay more than non-business ones for a reduction in travel time. Non-business passengers are more prone to using public transport than business travelers, although both categories of passengers exhibit a strong aversion to the train-bus alternative.
[17]	Bari airport and Brindisi airport in Apulia region in Italy	Nested logit, mixed multinomial logit, and mixed nested logit	The airport choice depends on price and quality of air services offered at a specific airport, but also on the time and cost required to access it. Travel costs have a lower (negative) influence on the utility of business travellers than for non-business ones. In all the proposed scenarios, car (passenger) remains the alternative with the largest predicted market share.
[18]	Germany, Netherlands, and Belgium	Conditional logit model	People strongly prefer a departure airport situated in their own country. Factors that influence the airport choice: the number of carriers, the number of flights, dominance of LCCs (positive effect), a negative effect of travel time.
[19]	Istanbul Airport, Istanbul, Turkey	Fuzzy level based weight assessment—weighted aggregated sum product assessment—Heronian mean operators model	Underground metro has the highest score among the alternatives, followed by light rail transit, bus rapid transit, and premium bus services. Various factors including financial, operational, environmental, and project-specific characteristics lead to a problem setting where many uncertainties should be addressed.
[20]	Ataturk International Airport in Istanbul, Turkey	Three models for both multinomial and mixed logit model	Destination type as international or domestic affected the airport access mode choice. For domestic travel, car ownership increases use of car. Passengers on international destinations value time more than domestic travellers, while the influence of cost is similar. The reliability of mass transport modes can be marketed to passengers to increase their uses.
[21]	China's Bay Area with three airports (Hong Kong, Shenzhen and Zhuhai)	A multinomial logit model, a random forests algorithm, and deep reinforcement learning	Bonus or cash voucher for taxi or rental car could improve the ground service frequency. Hesitating customers may be attracted by a low price, high frequency ground service. Recording the page view would help airlines and airports to easily discover hesitancy.
[22]	Catchment area is Switzerland, and 16 airports in Switzerland, France, Italy, Germany and Austria.	Lognormal hurdle model	First, the results indicate that given the same levels of income and environmental concern, a person voting for the Green Party is less likely to fly than voters of the other major parties. Second, who lives closer to airports, in particular to large ones, has more air travel. Third, persons with higher environmental concern are less likely to travel by air and if they still do, they travel less.
[23]	Cairns, Australia	Discrete choice model	Leisure tourists' travel mode choice for dispersal, and the significance of destination in these choices. The dispersal of air leisure arrivals can be facilitated and stimulated by public transport.

Table 1. *Cont.*

Reference	Case Study	Model Used	Main Findings—Results
[24]	London airports: Heathrow, Gatwick, Manchester, Stansted, and Luton	Descriptive statistic analysis based on survey	The role played by airport 'meeter-greeters' in a ground access context. 'Meeter-greeters' and percentage of total passengers is obtained for five observed airports and share of passengers traveling with them by market segment. The environmental and economic implication of 'meeter-greeters' for an airport and possible solutions.
[25]	Case study: from Taipei to Shanghai, Tokyo, and Seoul	Nested logit model and error components logit	The joint choice behavior of access, airports, and flights exploring interdependence between choice dimensions and traveler's heterogeneity Access time, access cost, and egress time are effective landside attributes, whereas fare and frequency are important flight attributes for the joint choice of access modes and flight routes.
[3]	Brisbane, Australia	Traditional multinomial logit (MNL) and mixed logit (MXL) models	Travel time, travel cost, the number of transfers, and the amount of luggage were found to play a significant role in airport access choice. The out-of-vehicle time is also important factor; but interestingly, walking time had a much greater influence than waiting time, because of carrying luggage. Familiarity with airport access modes have been shown to significantly influence the choice of access mode.
[26]	Newcastle upon Tyne	MNL models	The model explains passengers' mode choices in terms of access time, household car ownership, the size of the access group, and luggage count. Business travelers are more sensitive to access time than leisure passengers. Passengers to domestic destinations are found to be more sensitive to access time compared to international-bound passengers.
[27]	Athens International Airport	Discrete choice random utility model	The important factors for the ground access mode choice by airport employees are travel time and costs, and income. Employees are willing to use the metro/suburban rail service if competitive fares and travel time are provided.
[6]	Taiwan	Descriptive statistic analysis based on survey	Elderly air passengers prefer to ask family members to drive them to the airport, while general passengers prefer to take a taxi. The results also indicate that "safety" is the most important item in the choice of access mode and "user friendly" and "convenience for storing luggage" as the next most important items for the elderly. Elderly passengers are found to be less likely to use PT than private transport.
[28]	Seoul, Korea	Mixed logit model	Different characteristics were found in choosing the mode of transportation between business and leisure air passengers. Business passengers wanted a safe secured mode regardless of fare. Leisure passengers are more willing to use duty-free shops.
[29]	Japan's intl. hub airports	Binomial logit model	Service levels including travel time, waiting time, travel cost, departure timing from home, the arrival timing at the airport, and delay cost affects ground access mode choice.

Airport ground accessibility has been largely investigated in different ways as: access mode choice in the light of passengers' preferences and behaviors [9,12], modal split to determine market share [17], integrated airport choice and access mode choice, integrated choice of airport, airline and access mode choice in an airline type choice context—low-cost carriers and full-service carriers [18], modal split for relocated airports, or an assessment of the introduction of a new mode [10,16].

However, this work differs from the existing literature in providing comprehensive statistical analysis based on the survey conducted in different European countries covering heterogeneities of their transport systems in terms of mode characteristics and service supply. Taking into consideration that the survey sample size is very large (2199 respondents), diversity of passengers' behavior and attitudes towards airport access mode is captured. Moreover, this research investigates the impact of non-coordination of multimodal transport system by estimating explanatory variables that affect the mode choice behavior.

3. Data and Methodology

This section provides the methodology for determining travelers' habits. According to the obtained survey results, we performed a correlation analysis to determine the main questions that influence the multimodal travel choice for the airport access, which are used in MNL regression.

The comparison among multimodal trip alternatives have been distinguished by three proposed cases: (i) Case A in which the mode choice "Train" is defined as a reference category; (ii) Case B in which the mode choice "Combination of modes" is defined as a reference category; and (iii) Case C in which we applied a resampling technique and used "Combination of modes" as a reference category.

3.1. Description of the Survey

The survey was designed considering three parts related to mobility profile, travel preferences, and sociodemographic of travelers. The main scope of the survey was to "quantify the tradeoffs that users consider when selecting travel alternatives and identify traveler characteristics that reflect their emotions, attitude, and travel behavior" [30]. The survey was disseminated online due to COVID-19 pandemic restrictions, translated in five languages (Italian, Greek, Serbian, Spanish, and English).

In order to obtain reliable results and to ensure the quality survey process, a careful specification of survey procedure was designed. After identification of the main scope of the survey, the target respondents were identified as air travelers mainly from four countries involved in research, but also from other European countries, with required sample size of minimum 1200 respondents. The questionnaire design passed through several phases in which a team of researchers from Greece, Italy, Spain, and Serbia, based on literature research as well as researchers' previous experience, developed questions within multiple internal brainstorming sessions. That resulted in the questionnaire structure which enabled to obtain information related to: (i) the socio-demographics of travelers (i.e., gender, age, average income); (ii) the travelers' habits, travel purpose, and trips' frequency; and (iii) the factors that affect the choice of travel mode. After conducting a pilot survey, the questionnaire was refined and a final version with 25 questions (a few of which included several sub-questions) was obtained.

Finally, the data collection started on 31 March 2021 and lasted until 18 May 2021, with in total 2251 collected responses. For dissemination of the questionnaire, official social networks (e.g., LinkedIn), SYN+AIR's website and some similar projects' websites, portals concerning aviation, and different passengers' associations were used. Data collection was constantly monitored in order to obtain a quality sample as a prerequisite for reliable survey results. Through this consistent monitoring process, some challenges with the online survey were successfully avoided. For example, having too many unemployed respondents or students in a sample is a common pitfall in online surveys, or difficulties reaching the older population. In this research, such challenges were prevented with well-chosen distribution channels and constant monitoring of the sample. After noticing that some groups of respondents appeared in a sample more than expected, distribution channels were redirected in order to fill this gap (for example, after receiving high number of responses from female respondents, the questionnaire was distributed through one aviation portal whose followers are mainly men and gender inequality in the sample was fixed).

The obtained dataset was analyzed and in the cleaning process, 52 responses were rejected which resulted in a total of 2199 answers, which were further examined (194 answers from Spain, 719 from Greece, 444 from Italy, 562 from Serbia, and 280 from other counties). The fact that the questionnaire was offered in five languages (English, Italian, Greek, Serbian, and Spanish) additionally contributed to reaching the targeted sample and getting desired feedback from different groups of air passengers (different by ages, gender, trip purpose, frequency of travel, etc.), as well as to reaching this valuable sample size.

3.2. Correlation Analysis

For selected variables, we applied Pearson's correlation to determine meaningful correlations. The Pearson's correlation coefficient is a measure of the covariance between two variables X and Y, divided by the product of their standard deviations, as reported in Equation (1) [31]. Here, x_i, y_i are i element of the variables X and Y, n is the size of sample, and $\overline{x}, \overline{y}$ are the mean of variables X and Y.

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{y})^2}} \tag{1}$$

The Pearson correlation represents a linear association between two variables, which can take a value between −1 and 1, so that value −1 indicates a perfectly negative correlation, while 0 value indicates no correlation between two variables [31]. Since answers related to multiple-choice question were (usually) independent, we transformed them in a new binary variable, and we calculated the Pearson correlation among them with Phi coefficient. In this way, positive correlation Phi coefficient indicates a high number of common answers between two binary variables (both affirmative and negative answers). We considered only the correlation where the Pearson's coefficients greater than 0.1 are defined as positive correlation, while the values lower than −0.1 are defined as negative correlation.

3.3. Multinomial Logistics Regression

In this section, we provide a short description of MNL regression analyses that we used to determine the users' perspective for making multimodal choices in their travel, based on the outputs from survey. Based on correlation and descriptive analysis from the disseminated survey, we determined explanatory variables that affect the airport access mode choice. Consequently, the question related to mode choice ("If all of the following transport modes are available, which one would you choose to travel to/from the airport?") was analyzed to identify and understand the main travel attributes that determine the users' perspective for making multimodal travel choices.

MNL regression is conceptually similar as the binary logistics regression, but the main difference is that the method provides parameters related to the choice between more than two alternatives. In such a way, it examines the relationship between the dependent variable and a set of independent variables. To describe such type of dependent variable (i.e., question related to mode choice), the method needs to compare alternatives i, one by one, with the baseline category j. For example, in the case of baseline category logit, the log of ratio of probability is calculated as follows [32]:

$$log\left(\frac{P(category_i)}{P(category_j)}\right) = B_{i0} + B_{i1}x_1 + \ldots + B_{ik}x_k \tag{2}$$

where B_{i0} is the constant of i alternative, x_k are k explanatory variables, and B_{ik} is the parameter of alternative i related to x_k explanatory variables that can be binary, categorical, ordinal, or continuous.

4. Results

In this section, we report the main findings from the conducted survey, correlation analysis, and MNL regression. In the Section 4.1, we provided descriptive statistics of the considered questions from the survey related to the mobility profile and travel preferences of respondents. The results of the Cramer's V and Pearson correlations for questions related to the mode choice, as well as the factors that influence mode choice, are described in the Section 4.2. Finally, Section 4.3 is devoted to the results of the MNL regression, in which we distinguished three cases for determining explanatory variables that affect the traveler's choice.

4.1. Descriptive Statistics Related to Considered Questions from Survey

In this section, we focus on the descriptive analysis of the conducted survey. Through 2199 collected answers, we obtained the information of respondents related to the socio-demographic (i.e., gender, age, average salary), travel frequency, the factors that influence the travel mode choice, etc. Related to the socio-demographic characteristics, it can be observed that 54.43% of respondents were female, and 44.52% of them were male (the rest of respondents declared either as other or rather not say), with an average age of 39 years. In addition, most of the participants, 61.07%, have an average household income, while 20.55% of them have high income [30].

Some of the main findings of the survey are summarized as follows. The first part of the survey, related to mobility profile, analyzed the most common motives for traveling by airplane such as "mostly for business", "only for business (meetings, conferences, etc.), "mostly for leisure", and "only for leisure (vacation, visiting family, etc.)". According to the answers, "mostly for leisure" was selected as the most common purpose of travel for most of the respondents, resulting in 42.02%, Figure 1. On the other hand, the lowest number of respondents, 3.14% of them, selected "only for business".

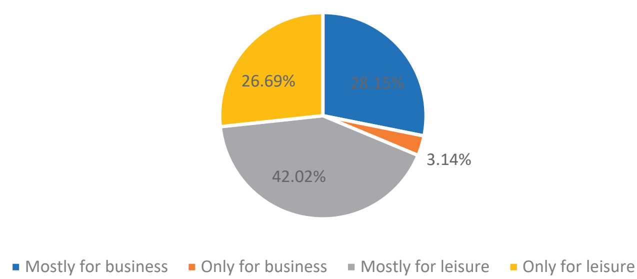

Figure 1. The most common motives for traveling by airplane.

The second part of the survey was related to the travel preferences of passengers, where respondents selected transport options for arriving to/from the airport among "train", "taxi (or ridesharing services like Uber of Lyft)", "metro", "combination of modes (bus or train)", "car (someone drops me off/pick me up)", "car (park at/near the airport)", "bus" mode choice alternatives. As expected, most of the respondents (40.11%) selected "car (someone drops me off/pick me up)", while "bus" was the chosen by the least number of respondents (2.59%), Figure 2.

Moreover, the respondents were able to determine the importance of the factors that influence their decision in selecting travel mode choice though the relative scale of importance (not important, less important, important, more important, and most important). These factors were related to the waiting time, travel time, travel costs, reliability, security, weather, crowdedness, trip purpose, and familiarity of the city. For example, the factor "reliability" was rated as "more important" and "most important" more than other factors, when making the mode choice, by 34.88% and 33.97% of respondents, respectively. In addition, the factor "travel time" was rated as "important" by 42.25% of participants when selecting the mode of transport. Furthermore, the factor "travel costs" was selected to be "important" when making the mode choice by 39.79% of the respondents, while the factor "waiting time" was selected as "important" by 42.20% of respondents. Furthermore, in all the cases, less than 10% of the answers rated factors "reliability", "travel costs", and "waiting time" as "not important". Therefore, these factors demonstrate high influence on the attitude and mode choice of travelers.

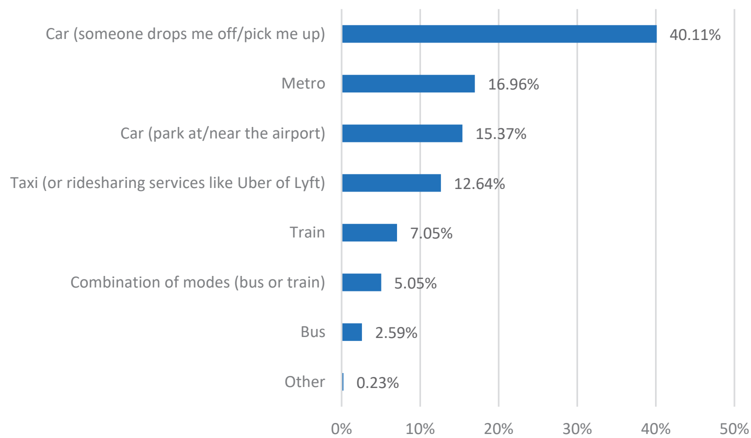

Figure 2. Travel preferences of passengers related to airport access mode choice.

4.2. Results of Correlation Analysis

The structure of the survey was made from the total of 44 variables (22 nominal string variables with more than 2 answer choices, 13 numeric (Likert) variables, 7 binary variables, and 2 continuous/scale questions (complete questionnaire can be seen in [30])). However, we concentrated on the questions related to the mode choice and the factors that influence mode choice. Related to those selected variables, since most of them are nominal, we first performed Cramer's V test to get an insight into the strength of the relationship between observed categorical variables. Figure 3 presents a heatmap with the results of Cramer's V test which measure association between the airport access mode choice and all other variables from the survey. Based on the obtained results, variables with Cramer's V test statistics value higher than 0.1 were further transformed into quantitative (dichotomous) categorical variables and Pearson's correlation was applied to determine meaningful correlations.

In Table 2, we reported the results of the meaningful correlations related to the mode choice selection among "Car (someone drops me off/picks me up)", "Car (park at/near the airport)", "Train", "Bus", "Metro", "Taxi (or ridesharing services like Uber or Lyft)", "Combination of modes (e.g., bus and train)", and "Other" mode choice alternative. Specifically, we reported the variables with a Pearson correlation coefficient greater than 0.14 in absolute value, while "bus", "combination of modes", and "other" mode choices have been omitted due to weak values of Pearson correlation. For example, the choice of the "Car (someone drops me off/picks me up)" alternative is positively correlated with female respondents who travel "only for leisure", have Greek residence, and belong to the age group between "18 and 29" years. On the other hand, it is negatively correlated with male respondents with Spanish residence, who travel "mostly for business", and are members of frequent flyer program (FFP). Furthermore, respondents with Greek residence were positively correlated with "comfort" as a factor for choosing the "Car (park at/near the airport)" alternative in Scenario B (Car or Train). The respondents with Serbian residence were negatively correlated to "travel cost" factor when choosing the "Car (park at/near the airport)" mode in Scenario B (Car or Train). Moreover, respondents with a permanent residence in Serbia were positively correlated with selecting the "Taxi (or ridesharing services like Uber or Lyft)" alternative for traveling to/from the airport, since taxi prices in Serbia are lower compared to other countries. On the other hand, the respondents with Serbian residence were negatively correlated with preferring public transport when traveling as a group of five or more people. Furthermore, the "train" mode involved only two main negative correlations, while "metro" mode showed positive correlations related to the influence of traffic congestion, when deciding the mode choice for reaching the airport [30].

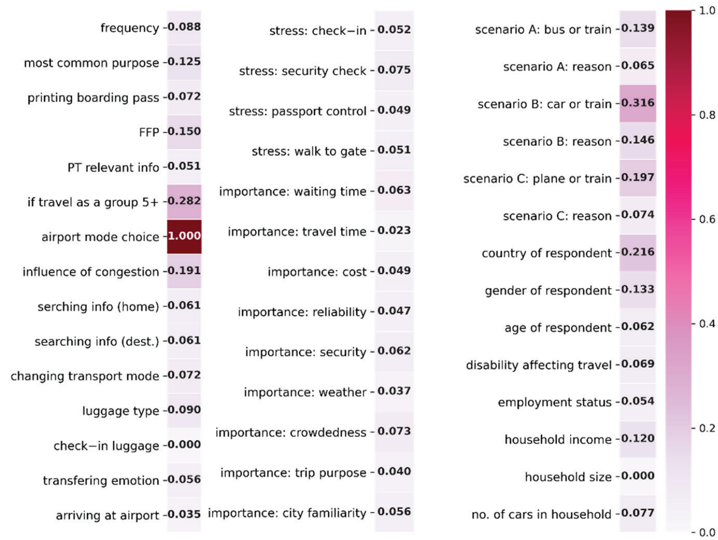

Figure 3. Heatmap of Cramer's V correlation between initial categorical variables and airport access mode choice.

Table 2. Main Pearson correlations related to the question (If all of the following transport modes are available, which one would you choose to travel to/from the airport?).

Mode Choice Alternative	Main Positive Correlations	Pearson Coeff. > 0.14 in Absolute Value	Main Negative Correlations	Pearson Coeff. > 0.14 in Absolute Value
Car (someone drops me off/picks me up)	Respondents that selected "Only leisure" as a purpose of travel	0.142	Respondents that selected "Mostly business" as a purpose of travel	−0.147
	Respondents with a permanent residence in Greece	0.185	Respondents that are members of frequent flyer program	−0.145
	Female gender respondents	0.182	Respondents with a permanent residence in Spain	−0.156
	Respondents 18 to 29 years	0.141	Male gender respondents	−0.171
Car (park at/near the airport)	Respondents that selected "Comfort" as a factor that influence the mode choice between "Car" or "Train" in scenario B	0.172	Respondents that preferred "Train" over "Car" in Scenario B	−0.224
	Respondents with a permanent residence in Greece	0.192	Respondents with a permanent residence in Serbia	−0.143
Train	No positive correlations greater than 0.14	-	Respondents that preferred "Plane" over "Car" in Scenario C	−0.162
			Respondents with a permanent residence in Greece	−0.162

Table 2. *Cont.*

Mode Choice Alternative	Main Positive Correlations	Pearson Coeff. > 0.14 in Absolute Value	Main Negative Correlations	Pearson Coeff. > 0.14 in Absolute Value
Metro	Respondents that selected "traffic congestion" as a factor that influence their mode choice when going at the airport	0.207	Respondents with a permanent residence in Greece	−0.150
	Respondents that preferred "Train" over "Car" in Scenario B	0.182		
Taxi (or ridesharing services like Uber or Lyft)	Respondents with a permanent residence in Serbia	0.166	Respondents that preferred public transport when travelling as a group of five or more people	−0.207

4.3. Results of Multinomial Logistics Regression

The multinomial analysis was applied to determine explanatory variables that affect the traveler's choice. As shown in Figure 4, the categorical dependent variable (question related to mode choice) is formed by seven alternatives with a different number of answers, ranging from 57 for the mode "Bus", and 882 for the choice "Car (someone drops me off/picks me up)". The independent variable considers the importance of significant attributes "waiting time", "travel time", "travel costs", and "reliability" in the question related to the factors that influence the mode choice, as well as socio-demographic information. In the case of the question as a dependent variable, we merged the alternatives in two choice sets: private and public transport. As shown in Figure 4, the considered sample of a total of 2083 cases was formed by 1220 respondents who preferred private modes of transport, and 863 that opted for public modes of transport.

To apply MNL regression, we proposed three cases as Case A, Case B, and Case C. In Case A, we referred to "Train" mode choice as a reference category, while in Case B we defined "Combination of modes" as a reference category. However, according to the results of the survey, we faced an unbalanced number of responses related to the transportation mode choice question (i.e., "If all of the following transport modes are available, which one would you choose to travel to/from the airport?"). Therefore, in Case C, we applied the resampling technique for capturing and analyzing the concept of multimodality in which we have the equal preferences (the equal number of responses) related to each travel mode alternative. For that purpose, we selected as a benchmark the total number of 111 answers related to the "Combination of modes" alternative. Since we faced a higher number of responses for car and taxi alternative, as well as a lower number of responses for metro, bus, and train alternatives, we applied a resampling technique in which we randomly extracted the answers from other transport modes to reach a balanced sub-sample. Specifically, we randomly selected 111 responses from the initial database related to the five travel mode choice alternatives (i.e., "Car (park at/near the airport)", "Car (someone drops me off/picks me up)", "Combination of modes", "Train/Metro/Bus", and "Taxi") to match with the 111 responses collected for "Combination of modes" alternative. In this case, from the initial 2199 responses, we randomly selected 111 replies of each transportation mode to match with the 111 responses collected for "Combination of modes" alternative, which corresponds to a total of 555 answers.

The MNL regression is reported by providing the comparison among the travel mode choices alternatives considering Case A, Case B and Case C. In general, the result of the MNL regression, considering all transportation alternatives, showed that the included variables can correctly predict the 40.3% of cases (variance scores $R^2 = 12.4\%$ by Cox and Snell, and $R^2 = 12.4\%$ by Nagelkerke), as reported in Table 3. However, we can conclude that the model is much more accurate for those who preferred the alternative "Car (someone drops me off/picks me up)", resulting in 91.8% correct predictions.

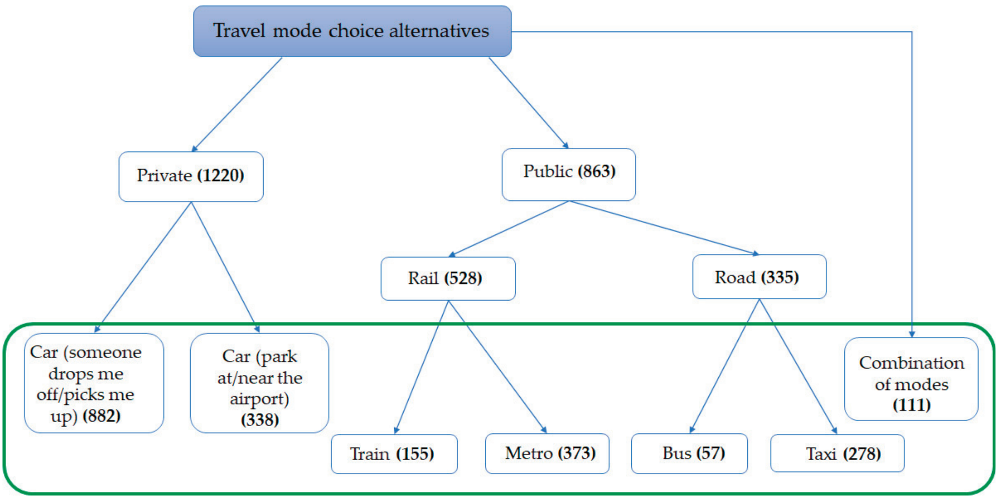

Figure 4. Multinomial choice related to public and private modes.

Table 3. Classification matrix of the MNL regression—Case A and Case B.

Observed	Predicted							
	Bus	**Car (Park at/near the Airport)**	**Car (Someone Drops Me off/Picks Me up)**	**Combination of Modes**	**Metro**	**Taxi**	**Train**	**% Correct**
Bus	**0**	0	55	0	2	0	0	0.0%
Car (park at/near the airport)	0	**1**	313	0	14	7	3	0.3%
Car (someone drops me off/picks me up)	0	0	**810**	0	44	23	5	91.8%
Combination of modes	0	0	97	**0**	10	2	2	0.0%
Metro	0	0	305	0	**51**	15	2	13.7%
Taxi	0	3	219	0	34	**21**	1	7.6%
Train	0	0	122	0	28	3	**2**	1.3%
Overall Percentage	0%	0.2%	87.6%	0%	8.3%	3.2%	0.7%	**40.3%**

As previously mentioned, the imbalance of replies showed the tendency of classifying most of the answers into category "Car (someone drops me off/picks me up)". Accordingly, the prediction of alternative "Car (someone drops me off/picks me up)" resulted in 810 replies over total 882 (see Figure 4), which led to the probability of 91.8% (i.e., the ratio between 810 and 882 is 0.918). However, other transportation mode alternatives showed a much lower percentage, less than 20%, such as the "metro" alternative with the prediction of 13.7%, i.e., 51 cases of 373 total. For example, "bus" and "combination of modes" alternatives had a prediction of 0% since the total answers for such alternative were 57 and 111, respectively.

4.3.1. Case A (Reference Category "Train")

The Case A was implemented to observe the differences between the various available travel alternatives with the "Train" mode as a reference category for public transport mode. For example, the comparison of the private and taxi alternatives versus train mode, regarding the factor "reliability", showed the preference of public alternatives versus private ones. This can be interpreted as a better response of the public transport system to react to any unexpected events, during the journey to and from the airport. Additionally, the rating of importance of the factor "waiting time", is lower for the alternative "train" versus the others. This result highlights the greater willingness of facing with higher waiting times for those who prefer to use the train, compared to the other modes.

Specifically, in Table 4, we report the detailed results of the MNL for Case A by distinguishing comparisons of other transportation mode alternatives with "Train" as a reference category as follows:

- Bus versus Train mode;
- Car (park at/near the airport) versus Train mode;
- Car (someone drops me off/picks me up) versus Train mode;
- Combination of modes (e.g., bus and train) versus Train mode;
- Metro versus Train mode;
- Taxi versus Train mode.

The column $Sig.^{c}$ reports the significance level—values less than 0.05 in Table 4 (or between 0.05 and 0.1 in Table 5) for the Wald statistic based on its Chi-square distribution, where the Wald statistic (considering variables having a single degree of freedom) is the squared ratio of B and its standard error $S.E.\ ^{a}$ The $Exp(B)$ can take the values between the lower and upper limits considering the confidence level $C.I.\ ^{d}$ of 95% (or of 90% in Table 5). Most of the analyzed variables were significant on 5% level and those are reported with 95% confidence intervals, while a smaller number of variables showed significance on the 10% level and are reported with 90% confidence intervals.

As observed from Table 4, the independent variables "business travel purpose", and "reliability", with a significant coefficient less than or equal to 0.1, negatively affected the probability of choosing the "Bus" versus "Train" odd ratio lower than 1 (OR < 1). Differently, a positive effect on the probability of choosing the "Bus" versus "Train" was related to female users (OR > 1). However, the significant variables for selecting "Car (park at/near the airport)" vs. Train mode alternative were related to factors such as "waiting time", "reliability", "travel cost", "business travel purpose", "female gender", and the "age group from 50 to 65". Therefore, one unit increase of the importance related to the factors "reliability", "travel cost", "business travel purpose", as well as the age group from 50 to 65, negatively affected the probability of selecting the "Car (parking near the airport)" versus "Train", Tables 4 and 5. On the other hand, the factors "waiting time", and female gender had a positive effect on the probability of selecting the "Car (parking near the airport)" versus "Train". In the second situation of selecting Car (someone drops me off/picks me up) vs. Train mode alternative, the "age group from 50 to 65", "business travel purpose", and one unit increase of the importance of the factor "Reliability", negatively affected the probability of choosing the "Car (someone drops me off/picks me up)" versus the "Train" mode, see Table 5. However, we can observe the positive effect of the one unit increase of the importance regarding the factor "Waiting time" and "female gender", on the probability of choosing a "Combination of modes" versus the "Train". In addition, one unit increase of the importance of the factor "waiting time", "female gender", and "high-income level" positively affected the probability of using the "Metro" versus "Train", while the business motivation to travel was related to a negative effect. In the situation of "Taxi" vs. the "Train" mode, one unit increase of the importance regarding the factor "waiting time", "female gender", and "high-income level" positively affected the probability of choosing "Taxi" vs. the "Train".

Table 4. Results of multinomial logistic regression (Case A)—95% confidence level.

Significant variables (questions) with $Sig.^c < 0.05$	B	$S.E.^a$ of B	Wald	$Sig.^c$	$OR = Exp(B)$	95% $C.I.^d$ for $Exp(B)$	
						Lower	Upper
Case A—Bus vs. Train							
Factor "reliability"	−0.418	0.179	5.456	0.019	0.658	0.463	0.935
Female gender	0.713	0.335	4.536	0.033	2.040	1.059	3.931
"Only business" as a motive for traveling	−0.929	0.394	5.546	0.019	0.395	0.182	0.856
Case A—Car (park at/near the airport) vs. Train							
Significant variables (questions) with $Sig.^c < 0.05$	B	$S.E.^a$ of B	Wald	$Sig.^c$	$OR = Exp(B)$	95% $C.I.^d$ for $Exp(B)$ Lower	Upper
Factor "waiting time"	0.383	0.113	11.382	0.001	1.466	1.174	1.831
Factor "travel cost"	−0.331	0.101	10.835	0.001	0.718	0.590	0.875
Female gender	0.847	0.219	15.004	0.000	2.333	1.520	3.581
Case A—Car (someone drops me off/picks me up) vs. Train							
Significant variables (questions) with $Sig.^c < 0.05$	B	$S.E.^a$ of B	Wald	$Sig.^c$	$OR = Exp(B)$	95% $C.I.^d$ for $Exp(B)$ Lower	Upper
Factor "waiting time"	0.434	0.103	17.796	0.000	1.543	1.261	1.887
Female gender	1.194	0.199	35.866	0.000	3.300	2.233	4.878
Age from 50 to 65	−0.469	0.227	4.247	0.039	0.626	0.401	0.977
"Only business" as a motive for traveling	−0.638	0.197	10.461	0.001	0.528	0.359	0.778
Case A—Combination of modes vs. Train							
Significant variables (questions) with $Sig.^c < 0.05$	B	$S.E.^a$ of B	Wald	$Sig.^c$	$OR = Exp(B)$	95% $C.I.^d$ for $Exp(B)$ Lower	Upper
Factor "waiting time"	0.318	0.144	4.869	0.027	1.375	1.036	1.824
Case A—Metro vs. Train							
Significant variables (questions) with $Sig.^c < 0.05$	B	$S.E.^a$ of B	Wald	$Sig.^c$	$OR = Exp(B)$	95% $C.I.^d$ for $Exp(B)$ Lower	Upper
Factor "waiting time"	0.365	0.111	10.876	0.001	1.441	1.160	1.790
Female gender	0.474	0.216	4.826	0.028	1.607	1.052	2.453
High household income	0.475	0.230	4.281	0.039	1.608	1.025	2.522
"Only business" as a motive for traveling	−0.438	0.212	4.281	0.039	0.645	0.426	0.977
Case A—Taxi vs. Train							
Significant variables (questions) with $Sig.^c < 0.05$	B	$S.E.^a$ of B	Wald	$Sig.^c$	$OR = Exp(B)$	95% $C.I.^d$ for $Exp(B)$ Lower	Upper
Factor "waiting time"	0.497	0.118	17.799	0.000	1.643	1.305	2.070
Factor "travel cost"	−0.339	0.104	10.749	0.001	0.712	0.581	0.872
Factor "reliability"	−0.239	0.122	3.859	0.049	0.787	0.620	0.999
Female gender	0.807	0.227	12.613	0.000	2.241	1.436	3.499

a. Standard Error; *c*. Significance level; *d*. Confidence Interval.

Table 5. Results of multinomial logistic regression (Case A)—90% confidence level and significance level between 0.05 and 0.1.

Significant variables (questions) with 0.5 < *Sig.* [c] < 0.1	*B*	*S.E.* [a] of *B*	Wald	*Sig.* [c]	$OR = Exp(B)$	90% *C.I.* [d] for $Exp(B)$	
						Lower	Upper
Case A—Car (park at/near the airport) vs. Train							
Factor "reliability"	−0.220	0.118	3.484	0.062	0.803	0.660	0.975
Age from 50 to 65	−0.476	0.257	3.440	0.064	0.621	0.406	0.950
"Only business" as a motive for traveling	−0.390	0.218	3.206	0.073	0.677	0.473	0.970
Case A—Car (someone drops me off/picks me up) vs. Train							
Factor "reliability"	−0.199	0.107	3.463	0.063	0.819	0.687	0.978
Case A—Combination of modes vs. Train							
Female gender	0.470	0.273	2.972	0.085	1.601	1.020	2.509
Case A—Taxi vs. Train							
High household income	0.419	0.241	3.030	0.082	1.520	1.021	2.264

a. Standard Error; *c*. Significance level; *d*. Confidence Interval.

4.3.2. Case B (Reference Category "Combination of Modes")

Case B of the multinomial analysis was carried out to investigate the attitudes of respondents related to the choice between one mode and combination of modes for accessing the airport. Therefore, the chosen reference alternative was "Combination of modes". According to the results, in this regression we observed that, in some cases, the factor "travel time" assumed a lower importance for respondents who preferred the solution "Combination of mode". Such result perceives a major travel time of such multimodal travel alternative, also because it did not include any form of coordination between transportation systems. More detailed results of the Case B by distinguishing comparisons of transportation mode alternatives with "Combination of modes" as a reference category were investigated as follows:

- Bus versus Combination of modes;
- Car (park at/near the airport) versus Combination of modes;
- Car (someone drops me off/picks me up) versus Combination of modes;
- Metro versus Combination of modes;
- Taxi versus Combination of modes.

The results of the MNL regression for Case B related to the significance level with values less than 0.05 are reported in Table 6, while in Table 7 the values considering the significance level between 0.05 and 0.1 are reported. According to Table 6, we can observe that one unit increase of the importance regarding the factors "waiting time" and "reliability" negatively affected the probability of using the "Bus" versus the "Combination of modes", while the factor "travel time" had a positive effect. One unit increase of the importance related to the factors "travel cost" and "age group from 50 to 65" negatively affected the probability of preferring the "Car (parking near the airport)" versus the "Combination of modes". On the other hand, the importance of the factor "travel time" had a positive effect on choosing "Car (parking near the airport)" versus the "Combination of modes". Concerning the results of the comparison between the mode "Car (someone drops me off/picks me up)" versus the "Combination of modes", it was observed that "female gender" had a positive effect, while belonging to the age group from 50 to 65 shows a negative influence. However, the probability of using the "Metro" versus the "Combination of modes" was positively influenced by a high income level. One unit increase of the importance regarding the factor "travel time", "high income", and "business purpose" positively affected the probability of choosing "Taxi" versus the "Combination of modes", while the factor "travel cost" had a negative effect. In addition, one unit increase of the importance regarding the factors "waiting time" and "female gender" negatively affected the probability of choosing the "Train" versus the "Combination of modes".

Table 6. Results of multinomial logistic regression (Case B)—95% confidence level.

Significant variables (questions) with $Sig.^{c} < 0.05$	B	$S.E.^{a}$ of B	Wald	$Sig.^{c}$	$OR = Exp(B)$	95% $C.I.^{d}$ for $Exp(B)$ Lower	Upper
Case B—Bus vs. Combination of Modes							
Factor "travel time"	0.450	0.194	5.384	0.020	1.569	1.072	2.294
Factor "reliability"	−0.371	0.188	3.888	0.049	0.690	0.477	0.998
Case B—Car (Park at/near the Airport) vs. Combination of Modes							
Factor "travel time"	0.292	0.133	4.823	0.028	1.339	1.032	1.738
Factor "travel cost"	−0.252	0.111	5.100	0.024	0.778	0.625	0.967
Case B—Car (Someone Drops Me Off/Picks Me Up) vs. Combination of Modes							
Female gender	0.724	0.215	11.313	0.001	2.062	1.352	3.143
Case B—Metro vs. Combination of Modes							
High household income	0.799	0.292	7.458	0.006	2.223	1.253	3.943
Case B—Taxi vs. Combination of Modes							
Factor "Travel cost"	−0.260	0.115	5.139	0.023	0.771	0.616	0.965
High household income	0.743	0.301	6.085	0.014	2.101	1.165	3.791
"Only business" as a motive for traveling	0.548	0.257	4.550	0.033	1.730	1.045	2.862
Case B—Train vs. Combination of Modes							
Factor "waiting time"	−0.318	0.144	4.869	0.027	0.727	0.548	0.965

a. Standard Error; *c*. Significance level; *d*. Confidence Interval.

Table 7. Results of multinomial logistic regression (Case B)—90% confidence level and significance level between 0.05 and 0.1.

Significant variables (questions) with $0.5 < Sig.^{c} < 0.1$	B	$S.E.^{a}$ of B	Wald	$Sig.^{c}$	$OR = Exp(B)$	90% $C.I.^{d}$ for $Exp(B)$ Lower	Upper
Case B—Bus vs. Combination of modes							
Factor "waiting time"	−0.322	0.187	2.973	0.085	0.725	0.532	0.987
Case B—Car (park at/near the airport) vs. Combination of modes							
Age from 50 to 65	−0.487	0.288	2.860	0.091	0.614	0.382	0.988

Table 7. *Cont.*

Case B—Car (someone drops me off/picks me up) vs. Combination of modes							
Age from 50 to 65	−0.480	0.261	3.377	0.066	0.619	0.402	0.952
Case B—Taxi vs. Combination of modes							
Factor "travel time"	0.233	0.137	2.871	0.090	1.262	1.007	1.582
Case B—Train vs. Combination of modes							
Female gender	−0.470	0.273	2.972	0.085	0.625	0.399	0.980

a. Standard Error; *c*. Significance level; *d*. Confidence Interval.

4.3.3. Case C

In Case C, we referred to the "Combination of modes" alternative, and then we randomly extracted the same number of cases from other transport modes to reach a balanced sub-sample. Furthermore, the number of alternatives was reduced by merging the alternatives "Metro", "Bus", and "Train" in one new dummy category. In summary, the rating of the factor "travel time" positively affected the choice of the "Car (park at/near the airport)", while the importance of "travel cost" and "reliability" pointed out negative influence. The category "Train/Metro/Bus" emerged as the positive effect of the importance related to the factor "reliability". The higher rating of the variable "waiting time" positively affected the probability of choosing the alternative Taxi versus the combination of modes. On the other hand, the importance of factor "travel cost" showed a negative influence. Next, we report the results of the MNL regression of the Case C for the following situations:

- Bus versus Combination of modes
- Car (park at/near the airport) versus Combination of modes
- Train/Metro/Bus versus Combination of modes
- Taxi versus Combination of modes

According to the results in Table 8, the resampling strategy reached a lower percentage of total correctly predicted cases compared to the regression considering the whole sample (34.1 < 40.3). However, considering the prediction of each alternative, the obtained percentage was more uniformly distributed. The variables included in the model correctly predicted 34.1% of cases. Furthermore, in this case, results were more accurate for those who preferred the alternative "Car (someone drops me off/picks me up)" (48.6%) than for other modes. Additionally, the results of the model are reported considering the variance scores $R^2 = 16\%$ by Cox and Snell, and $R^2 = 16.7\%$ by Nagelkerke. Accordingly, we can observe that the obtained variance scores of the multinomial logistic regression considering resampling strategy were higher than the multinomial logistic regression of the whole sample. This is due to the equal number of 111 replies that were initially randomly selected for each one of the 5 considered alternatives. In this way, the probability of selecting each one of the considered alternatives was much more accurate, as well as the total prediction regarding the ratio of predicted and total number of responses for each alternative (e.g., the correct prediction of 54 for "Car (someone drops me off/picks me up)" over 111 of the total answers led to the overall prediction of 48.6%), as reported in Table 8.

Further, we report the results of the MNL regression of the Case C related to the significance level (lower than 0.05) in Table 9, and significance level between 0.05 and 0.1 in Table 10. Considering the comparison between the alternatives "Car (someone drops me off/picks me up)" versus "Combination of modes" in Table 9, we can observe only one significant factor as "female gender" that showed a positive influence on this mode choice. However, one unit increase of the importance regarding the factor "travel time" positively affected the probability of using the "Car (park at/near the airport)" versus the "Combination of modes". On the other hand, a negative effect was related to the independent variables concerning the importance of "travel cost" and "reliability", while belonging to the age group from 50 to 65 showed a negative influence. Additionally, a single significant independent variable emerges as the result of the comparison between the "Train/Metro/Bus" versus "Combination of modes". In particular, this independent variable regarded the importance of "reliability", where a growing level of the latter positively affected the probability of choosing the group of three modes of transport "Train/Metro/Bus". Moreover, one unit increase regarding the variable "waiting time", and business travel purpose positively affected the probability of choosing the "Taxi" versus the "Combination of modes". Differently, the importance of the variable "travel cost" showed a negative effect.

Table 8. Classification matrix of the MNL regression—Case A and Case B.

Observed	Predicted					
	Car (Someone Drops Me off/Picks Me up)	Car (Park at/near the Airport)	Train/Metro/Bus	Taxi	Combination of Modes	% Correct
Car (someone drops me off/picks me up)	**54**	19	12	13	13	48.6%
Car (park at/near the airport)	29	**33**	10	23	16	29.7%
Train/Metro/Bus	26	10	**39**	24	12	35.1%
Taxi	25	14	15	**50**	7	45.0%
Combination of modes	36	13	31	18	**13**	11.7%
Overall Percentage	30.6%	16.0%	19.3%	23.1%	11.0%	**34.1%**

Table 9. Results of multinomial logistic regression (Case C)—95% confidence level.

Case C—Car (as Passenger) vs. Combination of Modes							
Significant variables (questions) with $Sig.^{c} < 0.05$	B	$S.E.^{a}$ of B	Wald	$Sig.^{c}$	$OR = Exp(B)$	95% $C.I.^{d}$ for $Exp(B)$	
						Lower	Upper
Female gender	0.896	0.296	9.181	0.002	2.449	1.372	4.372
Case C—Car (park at/near the airport) vs. Combination of modes							
Significant variables (questions) with $Sig.^{c} < 0.05$	B	$S.E.^{a}$ of B	Wald	$Sig.^{c}$	$OR = Exp(B)$	95% $C.I.^{d}$ for $Exp(B)$	
						Lower	Upper
Factor "travel costs"	−0.357	0.141	6.436	0.011	0.700	0.531	0.922
Age from 50 to 65	−0.812	0.398	4.174	0.041	0.444	0.204	0.968
Case C—Taxi vs. Combination of modes							
Significant variables (questions) with $Sig.^{c} < 0.05$	B	$S.E.^{a}$ of B	Wald	$Sig.^{c}$	$OR = Exp(B)$	95% $C.I.^{d}$ for $Exp(B)$	
						Lower	Upper
Factor "waiting time"	0.386	0.166	5.434	0.020	1.472	1.063	2.037
"Only business" as a motive for traveling	0.647	0.313	4.277	0.039	1.910	1.034	3.528

a. Standard Error; *c*. Significance level; *d*. Confidence Interval.

Table 10. Results of multinomial logistic regression (Case C)—90% confidence level and significance level between 0.05 and 0.1.

Significant variables (questions) with $0.5 < Sig.^{c} < 0.1$	B	$S.E.^{a}$ of B	Wald	$Sig.^{c}$	$OR = Exp(B)$	90% $C.I.^{d}$ for $Exp(B)$	
						Lower	Upper
Case C—Car (park at/near the airport) vs. Combination of modes							
Factor "travel time"	0.283	0.161	3.101	0.078	1.328	1.017	1.732
Factor "reliability"	−0.277	0.164	2.842	0.092	0.758	0.578	0.994

Table 10. *Cont.*

Case C—Train/Metro/Bus vs. Combination of modes							
Factor "reliability"	0.284	0.169	2.809	0.094	1.328	1.005	1.756
Case C—Taxi vs. Combination of modes							
Factor "travel costs"	−0.246	0.140	3.112	0.078	0.782	0.621	0.985

a. Standard Error; *c*. Significance level; *d*. Confidence Interval.

5. The Impact of Non-Coordination in Multimodal Trip

The results of the three cases of MNL analysis reflect the actual situation related to transportation mode choices, which is dominated by non-coordination among TSPs. To assess the impact of non-coordination, we performed further analysis, starting from the interpretation of the coefficients in the MNL analysis related to the statistically significant independent variables. Specifically, we were able to estimate the change in the probability of a certain choice by varying a single independent variable and keeping all the others constant. In this way, we estimated the Likert scale factors that influenced mode choice ("How much do the following factors influence your choice of mode when travelling to and from the airport?"), such as "waiting time, and "reliability".

Thus, we represented the ranking of the airport access mode choice preference, according to the importance of the factor "waiting time". According to Figure 5 and the presented ranking, the probability of choosing "Taxi" was higher than the probability of choosing other modes when the factor "waiting time" was highly important, while the choice of the "Bus" mode would correspond to the situation in which "waiting time" was a less important factor. Such outcome confirms what is expected regarding the preference of private transport modes and "Taxi" compared to "Train", in which travelers prefer these mobility solutions when the waiting time or delays are of significantly higher importance. For example, the probability of choosing "Taxi" is 1.6 times higher than choosing "Train". This can be observed from the results of the MNL analysis regarding the OR ratio, as follows:

- Combination of modes, (*OR* = 1.375)
- Metro, (*OR* = 1.441)
- Car (park at/near the airport), (*OR* = 1.466)
- Car (Someone drops me off/pick me up), (*OR* = 1.543)
- Taxi, (*OR* = 1.643)

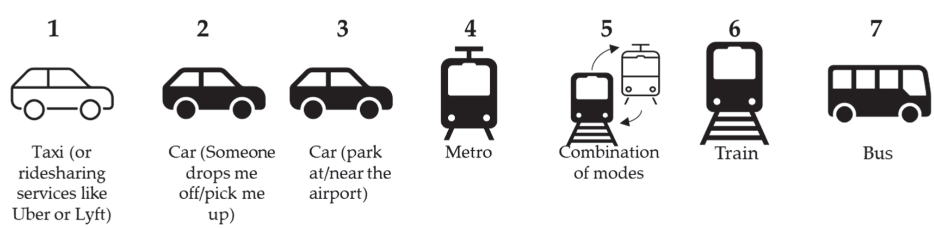

Figure 5. The ranking of mode choices regarding the importance of factor "waiting time".

We can state that the importance of "waiting time" resulted in higher probability of choosing "Car (as passengers or drivers)" in the case of the non-coordination among TSPs. However, we can expect lower waiting time if the coordination among TSPs exists, and therefore, higher probability of choosing the public transport modes.

In Figure 6 is reported the ranking of mode choice according to the one unit increase in the importance of the factor "reliability". We can observe low preference regarding the choice of "Bus", "Car", and "Taxi" mode, according to the one unit increase of the factor reliability factor. Therefore, we can state that the importance of the reliability causes the higher probability of choosing public modes versus private ones, which can be confirmed with the B values, as follows:

- Bus, (B = −0.418)
- Taxi, (B = −0.239)
- Car (park at/near the airport), (B = −0.220)
- Car (Someone drops me off/pick me up), (B = −0.199)

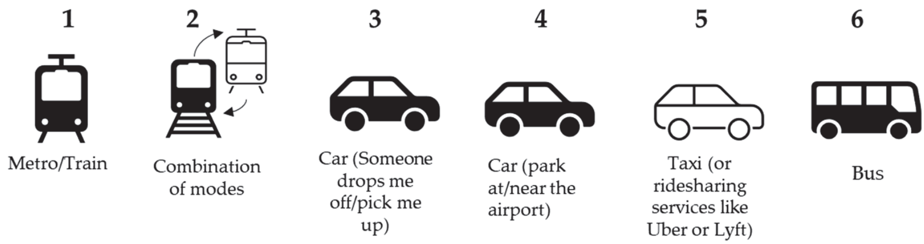

Figure 6. The ranking of mode choices regarding the importance of factor "reliability".

The importance of factor "reliability" is not significant when comparing "Car (as passengers)" with "Combination of modes" in Case C. Moreover, the comparison of "Car (as driver)" with "Combination of modes" in Case C, results in a lower negative value of parameter B = −0.277. Accordingly, we can observe the higher importance of the factor reliability for "Combination of modes", as well as a positive effect for the union of "Train/Metro/Bus" which resulted in B = 0.284. On the other hand, the importance of the factor "reliability" for "Bus" mode is lowest due to the following reasons: (i) the importance of the factor "reliability" for Bus mode is lower than "Train" mode; (ii) the number of the answers for "Bus" mode is significantly lower than the other modes.

6. Conclusions

In this paper, we analyzed the travelers' mode choice behavior, as well as the factors that influence their airport access mode choice. The outcome of the analysis investigates the opportunities for shifting from private to public transport modes. Specifically, we provided correlation analysis to reveal the main factors that influence travelers' mode choice and consequently, we provided MNL regression to assess the probability of selecting certain travel modes. The model has been applied to a real-case study considering the answers obtained from the participants in the SYN+AIR's survey, [30].

According to the results of the meaningful correlations, the participants who preferred private solutions i.e., car (as passenger/driver) were positively correlated with: (i) traveling for leisure by plane; (ii) not being a frequent flyer; (iii) not being influenced by traffic congestion; (iv) having a low income level; and (v) traveling mostly for business (those who chose Taxi). Furthermore, these respondents belong to the younger age groups, and mostly, they perceive waiting and travel time as more important factors than reliability and travel cost, when choosing the airport access mode. On the other hand, travelers who opted for public modes, were positively correlated with: (i) being influenced by the traffic congestion (those who preferred train and metro); (ii) being mostly males (those who opted for the train); (iii) declaring a high income level; and (iv) preferring to travel within the groups of 5 people (those who preferred metro and Taxi), e.g., respondents from Spain (preferring Bus) and Serbia (preferring Taxi). These respondents perceived as more important the reliability and travel cost than waiting and travel time when choosing the airport access mode.

The main finding of our model confirmed previously found factors that influence the airport access mode choice, but also provided a new insight with respect to the multi-modal service with air transport as a main leg. Namely, after performing MNL regression, it was shown that the factor "reliability" has the highest importance for the Train/Metro union in the case of non-coordination among TSPs. Nevertheless, even in this case, we can notice that the reliability has a significant impact when selecting more than one transport mode choice. Thus, the impact of reliability should be supported even in the case of coordination among TSPs in order to minimize the risk of missing the flight. Furthermore, the waiting times in between should be balanced and reduced to improve passengers' experience. Attractive service features tailored to air passengers in terms of improved reliability and reduced waiting times will result in higher probability of choosing public transport modes, such as metro and train. Consequently, transport operators (and the environment too) should benefit from an increase of the share of travel demand shifted from the private car. Moreover, through the attributes (i.e., waiting time and reliability) are given the terms for establishing coordinated multimodal services in the practical applications. One of the practical applications is to push Mobility as a Service (MaaS) technology, where, in the process of journey planning, the MaaS operators receive the data from the network, TSP's services, and users' preferences to plan the journey and optimize travel routes. In this way, the reliability would be an important factor for providing a seamless journey considering the following perspectives:

- From users' perspective, we can introduce better reliability of public modes (bus, train, metro) by offering coordinated multimodal timetables. In the MaaS, this could be achieved through the demand prediction by obtaining information from passengers (i.e., origin, destination, time of requested service). At the same time, the better timetable coordination will result in reduced delays and waiting time.
- From public authorities' perspective, we can achieve better reliability by providing infrastructure accessibility that will encourage users to use more sustainable travel modes.
- From the policy making perspective, the reduced waiting times and increase of reliability could be helpful for shifting the demand from private cars to other travel modes.

However, this study has certain limitations related to the period of time when survey was conducted. Namely, the pandemic situation influenced passenger responses since they needed to recall to their last travel by air. Also due to pandemic, we were forced to conduct online survey. Although we are aware of the challenges of online surveys and tried to avoid pitfalls, we believe that a face-to-face survey would provide more reliable results.

For further developments, we aim to deepen the concept of the coordination among different TSPs considering the data that need to be shared among them, as well as the development of smart contract frameworks. This would enable the possibility for passengers to have a seamless D2D journey with "single ticket" experience, as well as accessibility to the real-time information in the multimodal chain.

Author Contributions: Conceptualization, A.C., S.G.P., K.K., M.K., S.D., D.B. and M.O.; methodology, S.G.P. and A.C.; validation, S.G.P. and A.C.; formal analysis, S.G.P., A.C. and K.K.; investigation, A.C., S.G.P., K.K., M.K., S.D., D. B. and M.O.; writing—original draft preparation, A.C.; writing—review and editing, A.C., S.G.P., K.K., M.K., S.D., D.B. and M.O.; visualization, A.C., S.G.P., K.K., M.K., S.D., D.B. and M.O.; supervision, M.O. All authors have read and agreed to the published version of the manuscript.

Funding: This work was developed within the project SYN+AIR: "Synergies between transport modes and air transportation". Both the research and the APC were funded by SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation program under grant agreement No. 894116.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Parts of this study were supported by SESAR Joint Undertaking within the project "Synergies between transport modes and Air transportation" (SYN+AIR) under grant agreement No. 894116 and the Ministry of Education, Science, and Technological Development, Republic of Serbia, as part of projects TR36033 and TR36002 (2011–2022).

Conflicts of Interest: The authors declare no conflict of interest.

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sustainability

Review

Social Sustainable Urban Air Mobility in Europe

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Abstract: The first step to steer passenger Urban Air Mobility (pUAM) towards the necessity of sustainability is to understand its impact on our urban transportation systems. This research emphasises the social footprint of passenger drones in scheduled operation as an early business model in European Functional Urban Areas. The literature review is guided by the corresponding Sustainable Urban Mobility Indicators (SUMI). The prospective impact which the introduction of pUAM has on the evaluation of European transportation systems regarding their affordability for the public, their inclusivity for mobility-impaired groups, their accessibility to commuters and the level of customer satisfaction is analysed. Furthermore, the impact of pUAM on the perceived quality of public urban space is examined. Results indicate the overall social footprint of passenger drones in European transport systems to be negative. Early market pUAM may lead to an unbalanced distribution of potential benefits, with services tailored to address only a limited number of citizens. Highlighting pathways for a societal benefiting technology, recommendations are provided for urban planning and city development.

Keywords: passenger UAM; urban planning; vertiports; affordability; inclusivity; accessibility; acceptance; satisfaction; SUMI

Citation: Biehle, T. Social Sustainable Urban Air Mobility in Europe. *Sustainability* **2022**, *14*, 9312. https://doi.org/10.3390/su14159312

Academic Editors: Vittorio Di Vito, Gabriella Duca and Raffaella Russo

Received: 27 June 2022
Accepted: 26 July 2022
Published: 29 July 2022

1. Introduction

In 2016, official sources estimated around 10,000 electric aircrafts would be in operation for the transportation of passengers in European urban airspaces by 2050 [1]. Today, investments in the respective technologies and regulatory frameworks have led to a more favourable outlook in market research. While first services are expected to launch in 2024, a broader market take-off is projected one year later, and about 160,000 vehicles are predicted to be in commercial operation by 2050 [2]. Meanwhile, efforts are being made to construct a digitalised and highly automated system for urban air traffic management (UTM/U-Space) to allow for the efficient and safe integration of these vehicles into our build environments [3]. From a mobility rationale, it is claimed that passenger Urban Air Mobility (pUAM) will reduce travel time with its integration in intermodal transportation networks, will lighten traffic congestion on the ground due to mode shifting into the air and will ultimately contribute to more sustainable transportation compared to ground-based alternatives due to the use of electric energy sources [4]. Moreover, it is argued that pUAM will not become an exclusive mode-choice for the few, but will soon become affordable, inclusive and accessible to the broader public, satisfying the transportation needs of common people and adding to the overall quality of life in our cities [5].

However, the vision of sustainable urban (air) mobility will not materialise by itself [6]. Initially, a contingency on sustainability effects regarding the use of drones for passenger transportation must be expected. This may include undesirable impacts on travel behaviour, e.g., increasing travel distances and, along with it, a renunciation of more sustainable ground transportation [7]. What is more, the introduction of low-level air traffic in conjunction with necessary transport infrastructure may increase social and welfare disparities among citizens [8]. To anticipate such planning difficulties, an ongoing technology assessment of pUAM becomes highly relevant in (European) transportation research. After all, it forms the precondition for urban planning authorities to make confident decisions on this new technological opportunity in cooperation with industry and communities.

This content analysis provides the audience with a systematic literature review on the social dimensions of sustainable transportation as depicted by the respective European Sustainable Urban Mobility Indicators (SUMI). To apply this framework, pUAM will be considered as a private mobility service complementary to public urban transportation systems. The expected impact of pUAM on the overall affordability, inclusivity and accessibility rating of urban transportation systems will be analysed. Further, the expected impact of pUAM on citizens' perceived satisfaction with the transportation system as well as on the perceived quality of public urban space is investigated. For the analysis, the criteria and aspects underlying the original SUMI are adopted on the specifics of pUAM. To further facilitate the analysis, the conceptual understanding of Functional Urban Areas (FUA) is applied. These comprises densely inhabited cities and their less densely populated commuter catchment area. Consequently, an FUA does not necessarily correspond to the administrative borders of a municipality or region [9]. In Europe, FUAs can be characterised by typically polycentric spatial structures and functionally linked areas, a minimum level of social and economic diversity, the existence of public spaces and greenery and a minimum level of public services, including the provision of public transport [10].

Business cases that are explicitly considered in the analysis are inner-city commutes and pUAM as linkage between city and periphery, e.g., satellite cities, suburban or rural areas [11]. Any service provision is thereby dependent on dedicated ground infrastructure for passenger access and egress, so called vertiports. The vehicles are considered piloted, battery-powered and able to vertically take-off and land (eVTOL) with two to five passengers on board. Booking will be conducted by digital means as part of the Mobility as a Service (MaaS) environment [12]. As it is expected for early market operation, pUAM services in this analysis are assumed to be scheduled operations between limited numbers of attractive, urbanised locations [13]. However, on-demand operation will be considered as part of the discussion and outlook. Within this analytical framework, substantiated prospects can help to assess the impact that an introduction of pUAM services will pose for the social sustainability assessment of European urban transportation systems. The findings may help authorities and planners to reflect a suitable role for pUAM in urban development and to steer a potential technology implementation towards the most vital target of sustainable mobility. What is more, the findings may contribute methodologically to a further adoption of SUMI towards new forms of aerial transportation.

2. Social Sustainability in Urban (Air) Transportation

In respect to the long tradition of transportation research, sustainable mobility is a relatively young concept which took off with the 1992 Green Paper of the European Commission "The Impact of Transport on the Environment: A Community strategy for "sustainable Mobility" [14]. The document acknowledged an increasingly problematic relationship between transport's positive effects on economic welfare and its negative environmental impacts. From there onwards, research and policy foci, methodological approaches as well as research questions have undergone substantial changes [15]. The ongoing observations regarding the impact of transportation on economy and society as well as their inter-relatedness have led to more integrated, interdisciplinary perspectives.

To describe this complexity and to illustrate trade-offs or synergies in the context of political decisions-making and urban planning, a large number of authors refer to the triad of ecological, economic and social pillars of sustainable mobility (e.g., [16–18]). While the economic pillar emphasises the role of mobility to ensure resource efficient production and development, the ambition of environmentally sustainable mobility contributes to the preservation of our climate, the conservation of non-renewable resources, the protection of biodiversity and the abatement of air, water and ground pollution. The social pillar ensures that mobility contributes to community cohesion by supporting equity, participation, health and security in society [19]. Socially sustainable mobility systems would therefore ensure that everyone is able to satisfy his or her transportation needs to engage in social and economic life on an equal basis. Therefore, the affordability of transportation for everyone is highly relevant, as well as its spatial accessibility and its inclusivity, e.g., for mobility-impaired groups [20].

Sustainable Urban Mobility Plans (SUMPs) offer the possibility to anchor these long-term goals for integrated freight and passenger transport, increased quality of urban life and environmental protection in transportation planning processes. SUMPs have been proposed by the European Commission as part of the "Action Plan on Urban Mobility" in 2009. In 2014, corresponding community guidelines have been approved by the European Union General Directorate for Mobility and Transport. Since 2019, in a revised edition, these guidelines constitute a fundamental methodological reference for municipal stakeholder initiatives to foster sustainable urban mobility in Europe and abroad [19]. SUMPs envisage to: (1) define a future vision and milestones for; (2) assess the current performance of; (3) implement measures in; and (4) re-evaluate an urban transportation system [21].

Sustainable Urban Mobility Indicators (SUMI) thereby reflect the conceptual understanding of sustainable urban transport in European policy and are the methodology to assess the actual impact of sustainable urban mobility planning practices described above. The set of these altogether 19 indicators is used to: (1) describe the performance of an overall urban transportation system or a certain aspect in a standardised form; (2) identify strengths and weaknesses in respect to certain policy targets or indicator thresholds; as well as to (3) assess the effectiveness of implemented policies and practices, e.g., by analysing a shift before and after the introduction of new means of transportation. The social dimension of sustainable urban transportation is reflected within five indicators, which measure the affordability of public transport for the poorest group, the inclusivity of public transport for mobility-impaired groups, the accessibility to mobility services for citizens, the satisfaction with public transport as well as with the quality of public spaces [21,22].

3. Methodology

This study utilises these SUMI to assess pUAM on its prospective impact on transportation systems in European FUAs. The methodological approach is to review the current literature to understand the prospective positive and negative implications of a pUAM introduction on the relevant indicators and, with this, on the overall social sustainability rating of urban transportation systems. It is to note, however, that the applicability and integrity of the indicators of pUAM characteristics have not yet been tested. In addition, while conventional air and water transportation is excluded from an assessment of a city's transportation system via SUMI, authors do call for the indicators to be revised and adopted with regard to the impact assessment of emerging transport technologies that stem from the electrification, automatisation and digitalisation of urban mobility [23]. To this end, this article makes its contribution.

3.1. Adoption of SUMI on pUAM Characteristics

Preliminary work through a specific framework for the evaluation pUAM stems from al Haddad et al. [24]. The authors suggest a list of Key Performance Indicators (KPIs) to assess the environmental, socio-economic and transport potential of pUAM in the FUAs of Upper Bavaria, Germany. To do so, a multi-criteria decision analysis was preformed whereby experts weighted indicators in terms of relevance and measurability. A final selection was made using a threshold method. In order to assess the validity of the selected KPIs, they compared them with the SUMI. On the social dimensions of sustainable urban transportation, mutually supported are the affordability or equity indicators and inclusivity indicator. Exclusive to SUMI remain the access to the mobility services indicator, the satisfaction with the transport service indicator and the impact on the quality of public spaces indicator. On the other hand, the quality of life/welfare indicator and the privacy disturbance indicator are proposed from the authors [24]. As both dimensions address specific characteristics of pUAM, they are going to be reflected in the following adoption of the original SUMI framework as recognized by the Directorate-General for Mobility and Transport of the European Commission. For indicator definitions see [25].

Affordability of public transport for the poorest group indicator: The indicator recognizes that public transport should be affordable for all parts of society in order to make them equally available in social and economic life. It is originally measured by the share of the poorest quartile of the population's household budget required to use public transport. In the context of pUAM, the indicator is particularly relevant as concerns exists that future services will only address high-income households or business travellers [26]. Hence, the expected cost structure and future price development of pUAM is reviewed from the literature in relation to average household incomes.

Inclusivity for mobility-impaired groups: The standard of this indicator is to ensure that people with reduced mobility can actively and fully participate in society rather than experience discrimination and accessibility restrictions on public transport due to their condition. From the original indicator, persons with reduced mobility can be quoted as "those with visual and audial impairments and those with physical restrictions, such as pregnant women, users of wheelchairs and mobility devices, the elderly, parents and caregivers using buggies and people with temporary injuries". Including people with intellectual disability or impairment in this definition, the issue of reduced mobility is prevalent for around 87 million people in the European Union alone [27]. Passenger UAM-related services should therefore not create new barriers for people with disabilities but allow them to enjoy the benefits of this innovation on an equal basis to customers without impairments.

Access to mobility services indicator: All neighbourhoods in a FUA should be meaningfully connected to public transport in order for people to equally participate in social and economic life. The indicator synthesises both averages, of how much distance people have to bridge in order to reach public transport services and how often these services are provided for the respective locality. Threshold values were defined for this in SUMI, e.g., in a metropolitan area, poor accessibility would be accorded if people need less than 10 min to reach their local railway, but only if this station is served less than four times an hour. Thus, the assessment of whether pUAM services meaningfully increase the access to urban transportation systems will depends foremost on the spatial distribution of vertiports, their reachability for customers within the respective catchment areas and their operational performance.

Satisfaction with public transport indicator: The satisfaction with public transport or a particular mode of transportation affects the actual usage. That in turn affects the potential to stimulate economic growth, social and territorial cohesion as well as positive environmental effects emerging from the public transportation system. According to SUMI, satisfaction can be measured by evaluating citizens' perceptions towards the affordability, safety, reliability and easiness to obtain a particular mode of transport. Hence, the more pUAM meets the expectations of the general public in these dimensions, the higher the satisfaction. Since services are not yet in place to evaluate actual user experiences, mainly results of acceptance research will be reviewed, in particular on the willingness to use and pay for pUAM.

Quality of public spaces indicator: The quality of public spaces affects mobility behaviour and urban life quality. Designed to analyse results from the European Commission's Urban Audit, the indicator pools the satisfaction of local populations with public spaces such as pedestrian areas and green spaces such as parks. In a broader understanding, public spaces may be evaluated by their openness, by the physical and environmental relief and the welcoming sensory perceptions they provide, as well as by their vibrancy of safety and control that citizens feel when engaging in these places (cf. [28]). Regarding UAM, a changing perception of these qualities due to UAM vertiports as well as a novel degree of low-level air traffic will be considered in the analysis, including privacy and welfare implications as suggested by al Haddad et al. [24]. Results from acceptance research and the planning-related literature will be reviewed.

3.2. Literature Analysis

To derive prospects for the social sustainability of early pUAM services, a literature-based content analysis was conducted [29]. The relevant documents have been selected from two databases: Web of Science and Google Scholar. To structure the selection process, a list of English keywords was created [30]. Those were initially derived from the content dimensions covered by the SUMI and substantiated by pUAM-specific keywords provided from the KPI description by al Haddad et al. [24]. Boolean operators were used to refine the search. From the initial pool of articles found via the search engines, additional documents were identified via cross-reference searches [31,32]. Table 1 provides an overview on the adopted definitions of SUMI for pUAM and the deployed keywords to structure the document research.

Table 1. Summary on the adopted SUMI framework for pUAM and keyword search.

SUMI Adopted for pUAM:	Research Focus:	Keywords for Database Search:
Affordability of pUAM for the poorest	Budget required to use pUAM on a regular basis for commuting and inner-city travel	uam AND affordability OR equity OR operating costs OR pricing OR demand
Inclusivity of pUAM for mobility-impaired groups	Prospective accessibility of pUAM services and infrastructure to persons with reduced mobility	uam AND inclusivity OR accessibility OR equality
Accessibility of pUAM services	Spatial distribution of vertiports and their performance.	uam OR vertiports AND accessibility OR scalability OR modal share OR location OR distribution OR capacity OR performance OR passenger handling
Satisfaction with pUAM	Perceived satisfaction of using pUAM, especially regarding its safety, affordability, reliability and easiness to obtain/convenience	uam AND user adoption OR acceptance OR satisfaction OR reliability OR affordability OR safety OR convenience
Impact of UAM on the quality of public spaces	Impact of pUAM and related infrastructure on the perceived satisfaction with public spaces and on the quality of urban life/welfare.	uam OR vertiports AND visual pollution OR privacy OR public spaces OR urban quality OR acceptance

Forty publications have been selected. Besides technical papers from academic and public agencies such as the European Union Aviation Safety Agency (EASA) and National Aeronautics and Space Administration (NASA), only peer-reviewed articles and, where necessary, conference papers were considered. In regard to the constant gain of knowledge in the field and to extend the scope of former reviews [4,33], this analysis focused on publications from the year 2020 onwards. Excluded from this guideline are key sources, e.g., the literature in fields with low publication density. The analysis was performed using the qualitative content analysis software Atlas.ti (version 9), which allows the management of larger data sets [34]. Codes were created deductively from the five indicators. The collected codes in each analysis category were then summarized on content level [35].

4. Results

On the basis of the literature analysis, prospects for the implementation of pUAM and its expected impact on the relevant indicator for the social sustainability of urban transportation systems in Europe is presented.

4.1. Affordability of pUAM

Studies attempting to estimate the price of pUAM suggest it to be below the per-kilometre price of existing helicopter point-to-point services but also far above the price of traditional taxi services [36,37]. More precise and comparable examples have been found only for eVTOLs with the capacity for three passengers, including one pilot. Based on a calculation made in the U.S. context, the median price per passenger and mile was found to be USD 7 net [38], corresponding to approximately EUR 3.78 per kilometre in 2021. Consequently, a 70 km flight from San Francisco to San Jose would cost around EUR 265 per passenger. A comparable study on the use of pUAM to supplement public transportation in the metropolitan FUA of Munich, Germany anticipates a price per passenger and kilometre of EUR 4.94. The charge for a 70-kilometre regional flight from Munich to the city of Ingolstadt would therefore be at least EUR 346 per passenger. For shorter inner-city trips or suburban connections, the study proposes additional basic fares up to EUR 20, making a 10-kilometre trip cost around EUR 70 per passenger [39]. The realism of these price calculations is in respect to the multitude of deduced and sometimes daring assumptions, e.g., regarding public funding of pUAM infrastructure, is hard to assess. Both examples underline, however, that early pUAM cannot compete with common modes of urban transportation (a monthly ticket for the extended Munich region Q1 2022 costs around EUR 230), let alone be affordable for regular commuting by broader parts of European society.

4.2. Inclusivity of pUAM for Mobility-Impaired Groups

The only reference found that specifically analyses the requirements of mobility-impaired groups for the design of pUAM services is published by NASA as a technical memorandum. It includes design considerations for the accessibility of ground infrastructure, vehicle access and cabin layout, consideration for in-flight operation and emergency response, as well as for the accessibility of digitally mediated information, ordering, booking and payment processes. The author emphasises the relevance of including the needs of mobility-impaired groups from the earliest stages onwards into the design and development process "of the overall system-of-systems network inherent in the UAM concept" to create path dependencies in favour of an inclusive transportation service [40] (p. 6).

If and to what extent current private sector development is anticipating this appraisal cannot be assessed from the literature. However, authors in the field of traditional aviation stress that handling passengers with special needs is posing additional cost that affects profitability and competition between airlines. This is particularly the case when closely timed operational processes are 'disrupted', or when customers are entitled free of charge to be guided by assistance personnel or to cargo space for mobility aids and medical equipment [41]. Accordingly, for pUAM services, trade-offs between the degree of inclusivity that could be offered and the financial requirements for infrastructure, vehicles and adopted operational procedures needed to realise it must be acknowledged.

In future, legal obligations might assist in shaping the inclusivity of pUAM services for mobility-impaired groups. For example, Straubinger et al. discuss pUAM as part of public transportation in Germany, implying an applicability of the National Public Transport Act [42]. This regulation obliges MaaS providers such as taxi, ride hailing or ride pooling companies with a fleet size from 20 vehicles to ensure at least 5% of their fleet to be accessible for disabled persons. Drawing this analogy, pUAM providers may become committed to certain inclusivity standards for their vehicles and infrastructure as a prerequisite for an operational approval from the licensing authority in the respective territory. Besides national level jurisdiction, European legislation may as well demand inclusivity standards for pUAM in future, as is currently in place for international aviation carriers, ships as well as rail transportation [43,44]. Finally, missing inclusivity standards might impact the overall customer satisfaction and public perception of pUAM negatively, hence pressuring manufactures and operations to adopt [13].

4.3. Access to pUAM Services

The impact of pUAM on the accessibility rating of urban public transportation systems in Europe will largely depend on the layout of vertiport networks, its reachability for customers and its performance.

4.3.1. Vertiport Placement

Regarding vertiport placement, studies apply demand-driven approaches, aiming to identify connections that will create reliable revenue in early market operation. The spatial distribution of vertiports is thereby dependent on the expectable number of trips between catchment areas in a city and the likelihood that people for these trips will choose pUAM over existing alternatives (cf. [44]). Primarily, high demand stems from agglomerations of commuters traveling between transportation hubs, residential and business districts of a metropolitan area [11]. As those are characterised by a certain density of transport infrastructure and saturation with public/private transport services, pUAM will likely represent an additional, potentially more time efficient mobility offer rather than filling accessibility gaps in urban transportation systems. While it would be through the commissioning and operation of vertiports in less connected neighbourhoods and remote suburbs that the establishment of pUAM would increase the transport accessibility rating in the respective areas, low demand counteracts such line of thoughts [45].

4.3.2. Reachability of Vertiports

The reachability of vertiports, e.g., in walking distance (a reasonable walking distance is quoted to be up to 2 miles/3.2 km [37]) presents a relevant factor for pUAM services to realise overall travel time savings compared to competing means of ground transportation [46]. However, the extent to which good reachability will be archived in complex urban environments is difficult to foresee. In the current state of research, vertiports are computed rather ideally into predefined catchment areas while planning vertiports is suggested to prove more challenging in real world scenarios [47–50].

As one particular planning constraint, the available space may prove a barrier. In regard to this, EASA already published technical design specifics for vertiports on the ground as well as on heights, such as business buildings and car parks for congested urban areas. Thereby, the vehicle touchdown and take-off area (TLOF) is covered by a rectangular funnel that widens towards the top. No obstacles may protrude into this volume for safety reasons. In the considered reference model (Volume Type 1), the height of the funnel is around 30 metres and the take-off and landing area is two times the diameter of the smallest circle enclosing the respective VTOL aircraft, which may be about 400 m^2 in size [51]. Thus, even when adding necessary facilities for passenger handling, the already iconic renderings of small landing pads on high-rise rooftops for a pUAM touch-and-go configuration in inner-city districts appears feasible. However, with the capacity for one vehicle only, these pads are significantly limited in their customer throughput rates. When anticipating the time for eVTOL landing and egress of three passengers, respectively for the boarding of three passengers and eVTOL departure with five minutes (process times are derived from Preis and Hornung [52]) each, 36 persons per hour could be serviced in scheduled operation under the most idealistic conditions. In mobility-on-demand operation, whereby more people want to land at inner-city vertiports in the morning or take off after work, higher costs, negative environmental impacts and, after all, operational inefficiencies are expectable from a repositioning of empty eVTOLs. Aiming for higher performance, Rimjha and Trani assume a size of around 8000 m^2 for a vertiport with parking stalls for eight eVTOLs, the necessary taxiing areas and one TLOF [53]. This equals to the size of a football field. Thus, when guaranteeing certain baseline capacities, the search for well-located infrastructure areas within walking distance can be expected to become significantly more difficult.

In addition to the availability and the financial feasibility of such spaces, the localisation and operation of vertiports is expected to become influenced by safety regulations as well as regulations for the protection of residents and the environment from harmful impact [33]. Similar to airport planning, research suggests that a reconciliation with public and residential interests, e.g., regarding urban fauna or protection from emissions, may impact administrative decisions on vertiport sizing and operations [54]. In this respect, residential acceptance becomes another relevant dimension of consideration. Besides externalities on neighbours from noise, also visual pollution, security concerns, privacy or increased traffic and congestions in the surrounding area may foster a rejection of vertiports in economically attractive catchment areas [55] p. 88. Factoring in these aspects, authors point out that operational requirements of vertiports in interchange to questions of residential acceptance could be lower on private industrial and commercially used spaces [42]. What is more, participatory planning approaches involving residents are suggested to help mitigate social vertiport planning obstacles, supporting the placement of vertiports in closer proximity to its potential beneficiaries [56].

4.3.3. Vertiport Frequencies

Last, to understand the impact of pUAM on the overall accessibility rate of an urban transportation system is the frequency with which vertiports and thus customers will be served by eVTOLs. Thereby, a vertiport must always be comprehended as a system bound to the capacities of its surrounding urban airspace and, hence, the U-Space management efficiency. However, the throughput capacity rate of a vertiport itself is primarily affected by (a) the vehicle specifics, including time for vertiport approach and departure, (b) the available size of the vertiport impacting the organising of ground operation and, of course, (c) turnaround times of the vehicles involving passenger handling [57]. The authors Preis and Hornung contribute to a better understanding on how these operational parameters affect the average wait time for pUAM passengers. Using an agent-based simulation, the authors conduct a sensitivity analysis that includes varying parameters regarding passenger demand, vertiport layout (pads, gates and stands) and processing times for eVTOLs and passengers. The results suggest that while each vertiport can handle a certain amount of constant demand with which low passenger wait times and reliable performance are conceivable, temporal peaks in demand have a significant impact on delay times (this may be less consequential for pUAM in scheduled operation and fixed ticket contingent, but significant for future on-demand operation and asymmetric arrival and departure requests). Much stronger, however, because growth is exponential after a certain tipping point, is the impact of increased processing time for vehicles and customers as well as a decreased availability of landing pads and gates on the average passenger delay. Hence, unexpected disruptions in vertiport operation or sudden airspace restrictions due to weather change or emergency operations may result in major delays for passengers [52].

4.4. Satisfaction with pUAM

As no large-scale pUAM services are available yet, the actual customer satisfaction cannot be assessed. However, studies on the willingness to hire or pay for pUAM once services are available can contribute to a more detailed understanding of the prospective satisfaction with pUAM. In summary, the general willingness to use air taxiing is low. For example, a population representative survey with 1000 respondents from Germany finds that only 18 per cent are open to use air taxis for their individual mobility [58] p. 6. However, Winter et al. show that the willingness to fly in an eVTOL increases the more this action is perceived as useful in a given situation [59] and al Haddad et al. show that the willingness to use pUAM increases the more the respondents associate the use of this service with a reduction in travel time [60]. Consequently, it is more comprehensible that a representative study commissioned by EASA with 3690 participants from six European metropolises concludes that, on average, 49 percent of respondents would at least try out and pay more for an air taxi under the condition that the given trip would be done in half the time compared to using a road taxi service [55] p. 62. Thus, the usefulness and advantageousness over its alternatives will be a decisive factor for customer satisfaction with pUAM.

4.4.1. Perceived Safety

In respect to the perceived safety, the before mentioned surveys from EASA shows that safety is rated the most prevailing concern for respondents from Europe [55] p. 73 while the respective survey from Germany shows that 53% of respondents disagree on the question if they would consider passenger transport with air taxis to be safe [58] p. 9. For the prospective satisfaction with pUAM services, this may be consequential. Lim et al. argue that a high safety perception and trust in eVTOLs will be most important for a positive user evaluation, especially for the initial stages of pUAM (priorities are expected to change in favor of service orientation once pUAM services proof their reliability) [61]. Adding to these results, statistical research suggest that respondents' feelings of safety towards eVTOLs strongly depend on how it is piloted. Chancey and Politowicz show in their study design that the willingness to use remotely piloted pUAM services is lower compared to services with an on-board pilot, as the latter is trusted more [62]. Similar results can be found regarding the future potential for fully automated [60] or autonomous [59] eVTOL operation in passenger transportation respectively. Authors indicate that the willingness to use and pay for pUAM decreases the lower the level of respondents' understanding towards the technology responsible for flight control [59,60]. Comparable results have been suggested in relation to automated long-haul aircrafts [63]. Thus, a safety perception towards the technology is somewhat a precondition to feel satisfied with pUAM. However, research suggests that trust levels or safety perceptions are significantly influenced by certain demographics. For example, it is suggested that younger persons have a higher affinity to vehicle automation while older persons have greater safety concerns. Further, it is suggested that women would simply feel more comfortable boarding an eVTOL with a pilot [64] or at least some sort of security monitoring in the aircraft cabin, respectively [60].

4.4.2. Perceived Affordability

Regarding the perceived affordability, studies aim to forecast not the actual cost of using a service for the individual (see chapter 4.1), but the threshold above which average customers become unsatisfied with the pricing scheme and unwilling to pay for the transport mode (cf. [65]). In alliance with prevailing transport planning approaches, this willingness to pay is conceptualised as a customer's trade-off between the value of travel time savings and financial cost [66]. Building on this presumption, Balac et al. included the option of Air Taxis in a mode choice simulation with agents representing 10% of the population from the canton of Zurich, Switzerland. They researched the impact of varying passenger handling times as well as travel speeds and costs. According to their research on the sample, the willingness to pay decreases significantly above a base cost of CHF 6 and a cost per kilometre above CHF 1.8 [67] (equalising to around EUR 1.8 in Q1 2022). For the USA, Goyal et al. modelled the sensitivity of customer demand to changes in the flight price for 10,000 randomly generated air taxi missions in ten metropolitan areas each and found that highest revenue in trade-off to customers' decreasing willingness to pay would be achieved at USD 2.50–2.85 per mile [38] (equalising to around EUR 1.5 to 1.7 per kilometre in Q1 2022). Concluding this, the price level up to which a broad customer satisfaction with pUAM services is suggested is more than 50% below prices to be expected from current estimations (cf. [38,39]). In addition, while it is commendable in terms of social sustainability that broad segments of the population were targeted in the respective research for acceptable pUAM pricing, Ahmed et al. emphasise the circumstance that the willingness to pay and therefore the satisfaction with service prices is highly dependent on the individual characteristics. For example, persons with an annual household income over USD 100,000 are expected to be more willing to pay up to USD 6.5 per mile for pUAM services [64], closely reaching the realistic cost estimation made by Goyal et al. [38].

4.4.3. Perceived Service Reliability

As research shows, the perceived service reliability, e.g., on-time performance [60] and low performance risks [68] are significant for the adoption of air taxis and the willingness to use all-electric passenger planes respectively. The latter decreases the more respondents are concerned about the risk of not being able to complete their journey satisfactorily, that problems during the journey cause cognitive stress, and/or that money will be lost due to any concomitant circumstances [68]. Thus, unforeseen operational constraints in connection with pUAM would likely impact the perception of the reliability of pUAM significantly and consequently, passenger satisfaction with the service. As shown in the previous chapter, unexpected disruptions in vertiport operation may result in such unwanted events and long passengers waiting. Additionally, airspace restrictions may prevent flights at short notice, e.g., due to bad weather or due to congestion from other urban air space users [52].

4.4.4. Perceived Easiness to Use

Last but not least, the perceived easiness to use pUAM receives consideration in research to improve customer acceptance and satisfaction. In the logic of the adopted indicator, highest customer satisfaction can be assumed when an easy booking and payment process is in place, vertiports can be accessed comfortably, waiting times are appropriate and overall service quality is high [11,60,61]. Regarding the booking process, the integration of pUAM into the MaaS environment is anticipated in most related research, which will allow booking and paying for the complete travel chain using a digital platform [7]. Travel can thus be expected to be comfortable for digital natives. Research on acceptable wait times for pUAM was not found. However, as scheduled pUAM operation is anticipated in this research and time saving is suggested to be a primary decision factor for customers, a threshold for acceptable wait time should be reached where it will become worthwhile for customers to choose another mode of transport in a given booking. As outlined before, these wait times will be impacted foremost by vertiport operations and airspace access [69]. Regarding service quality, Edwards and Price in their research for NASA on eVTOL Passenger Acceptance highlight several issues that could strongly impact customer satisfaction. To name a few, feelings of anxiety could arise from in-fight turbulence and gust responses; vehicle noise may cause discomfort; or outside-visuals may cause intimidation. Emphasising the yet small body of research on these aspects, the authors request further engagement in this field to ensure "that the passenger's first ride is not also their last" [13] p. 3.

4.5. Impact of pUAM on the Quality of Public Spaces

Similar to the evaluation of customer satisfaction, hints of a changing perception towards public spaces through pUAM can only be sustained through survey data and statistical model approaches. Regarding survey data, the before mentioned EASA study anticipates various impacts of vertiports as necessary ground infrastructure on the perceived quality of public spaces by the population. Respondents that were asked to rank their most relevant concerns related to close-by vertiports in their surrounding area rated noise (48%) and safety concerns (41%) most often. Furthermore, concerns regarding visual pollution (32%), increased inbound and outbound traffic (29%) and the occupation of spaces better used for living or recreation (28%) ranked high in concerns as well [55] p. 88. Regarding the impact of air traffic in the urban sky, in the before mentioned Sky Limits survey from Germany, 43% of respondents thought that air taxis would make urban spaces less pleasant to live in while just 22% of respondents were certain that passenger transport with air taxis would have a positive effect on the quality of life in cities. Asked about a future in which many people were to use air taxis, 61% of respondents rated it very or quite bad if air taxis would block the currently unobstructed view of the sky [58] p. 8, 14.

By creating a sample with 800 respondents from the same survey, Mostofi et al. developed a structural equation model to explain how the attitude of ordinary citizen towards air taxis is formed. They find that the expected impact of pUAM on the overall quality of life in cities is a significant predictor for the attitude respondents have towards eVTOL operation in public spaces. Further, they observe aesthetic dimensions such as the blocked view to the urban sky, noise and induced stress due to traffic movements above one's head as negatively impacting respondents' attitude. Derived from these findings, the authors advise pre-emptively minimising aesthetic risks in the choice and placement of vertiport infrastructure, in vehicle routing and in route frequentation [70].

To achieve this, however, urban planning practice must first embrace the lower urban airspace as a new subject for sustainable mobility planning. In this context, Kellerman et al.

review aspects of urban planning and city development covered in the contemporary literature and conclude that local planning authorities are considered unprepared to integrate three-dimensional air traffic (infrastructure) into existing planning practice. More precisely, two lines of research have not yet been integrated into a comprehensive discourse. On one hand, requirements for an UTM/U-Space are supposed to allow for high traffic volumes and operational safety of drones. On the other hand, the authors quote requirements for city planning authorities on the municipal or regional level to ensure a fair sharing of societal burden and individual benefits from drone related services. Cooperation will be required between different stakeholder groups such as commercial vertiport and air taxi operators, civil society, affected residents and customers. Proposed as a tool to facilitate this reconciliation are participatory planning practices [4]. However, it remains an open research question what issues participatory processes can mitigate effectively and how they can be implemented procedurally [71]. Relevant use cases are seen in the development of community guidelines for drones, to factor stakeholder interests in U-Space planning [56] or to mitigate drone related noise in a citizen science approach [72].

In the case of European regions and municipal authorities, the awareness for upcoming urban planning challenges and potential solutions is limited, as UAM developments in Europe have been focused strongly on model cities and regions. Those, however, have already advocated for a deciding role in the governance of local urban airspace, e.g., on the type of UAM services allowed as well as on the extent and territorial boundaries of services, including the decision on no-fly zones and the placement of take-off and landing sites [73]. While this legal authority on the regional or municipal level may facilitate greater adaption to local needs, other authors suspect the economic feasibility of pUAM to decrease due to extensive operational restrictions within and between cities and regions [74].

5. Discussion

Based on the results presented above, impacts of pUAM on the social sustainability rating of urban transportation systems in Europe can be discussed.

Findings on **affordability** provide a clear prospect. With about EUR 70 for a 10-km inner-city short trip (cf. [39]), most citizens will find pUAM too expensive for regular use. The introduction of pUAM would negatively affect the affordability rating of a European urban transport system. Nevertheless, authors argue positively for the development of a mass market and, along with it, decreasing consumer prices over the coming decades [54]. The current prime aspiration are public subsidies in the provision of local and regional UTM/U-Spaces as well as for urban take-off and landing sites for cargo and passenger drones. In analogy to conventional aviation air traffic management and road infrastructure, it is argued that such public engagement may foster a return on investments due to increased business activity [5]. In addition, greater engineering and operating efficiencies are forecasted over the next decades. This may include: lower costs for batteries and aircraft through mass production; extended aircraft operation through improved battery capacity and rapid charging; the substitution of on-board pilots through autonomous flight capability and a decreasing demand for staff on the ground through the automation of passenger handling processes [38]. In contrast to these long-term forecasts, the evolvement of a pUAM mass market may become hampered by improvements in alternative mobility services that occur parallel to the maturation of pUAM. Those might favour a shift to more efficient and sustainable transportation offers, e.g., ground vehicle automation in connection with relevant network expansion, efficiency improvements and price reductions in urban and regional ground transport. What is more, sustainable urban development must be quoted as countervailing trend, leading to increased functional diversity, shorter travel distances and less urban sprawl [7].

Drawing back on the literature regarding the **inclusivity of pUAM for mobility-impaired groups**, the likelihood and extent to which inclusivity requirements will become considered by eVTOL manufactures and vertiport architects cannot be assessed. Statements, for example on whether it will be possible to accommodate mobility aids such as prams or wheelchairs were not found. To avoid economic liabilities in early market entrance for the special designs and operational adjustments, the possibility is given, however, that pUAM services will not adhere to accessibility standards as provided to mobility-impaired groups in public transport. The inclusivity rating of the respective transport system would thus decrease. Nevertheless, companies aiming to integrate pUAM in urban settings must perforce cooperate with local planning authorities. Presuming their obligation to ensure social equality in transportation, the compliance of pUAM providers with minimum inclusivity standards might be enforceable [33]. What is more, dual use synergies from eVTOLs for civil medical services and military emergency response might support inclusive design features of certain vehicles [75].

Concluding the sub-chapter on the prospective **access to pUAM services**, the construction of small vertiports for a pUAM touch-and-go configuration in inner-city districts receives favourable regulations. However, available space significantly limits vertiport capacities. In respect to the SUMI, this low capacity for inner-city pUAM would not meaningfully impact the accessibility rating of the respective area. While the possibility should not be excluded, the likelihood to which larger vertiports with more relevant throughput rate will be placed central into attractive catchment areas seems far lower. Potential financial, legal and acceptance restraints connected to the construction and operation of larger transport infrastructure in densely populated areas must be mitigated [76]. Adding the envisioned integration of pUAM into the MaaS environment, it appears more likely that feeder traffic such as taxi services must be used by customers to access and leave vertiports, placed in less populated neighbourhoods. For vertiports in suburbs, outskirts and rural areas the situation might prove different. Access to the transportation system may be limited, favourable space for new infrastructures might be available and fewer legal and social restrictions may apply, but so is customer demand for pUAM. A regular connection of these stations as a prerequisite for improving the accessibility of the overall transport system of a FUA would prove to be costly and unlikely be executed in demand-driven pUAM planning approaches. To mitigate this shortcoming on frequency, authors point out that vertiport operators may become open accessible transportation hubs, e.g., including drone delivery and ground mobility services [54]. Especially for vertiports that are facing less demand, such a model could lead to higher utilisation, more overall pUAM network connections and thus increased accessibility for citizen.

Concluding the review on the prospective **satisfaction** of citizen with pUAM, safety aspects must be considered especially significant for early market operation. Thereby, studies suggest that the safety perception is rather subjective, meaning that pUAM can be perceived as safe from one person who might have a higher trust in new technologies while another feels more insecure and less willing to use the service [60]. The same rationale is true for the perceived affordability of services, influenced by varying income levels [64]. Consequently, the satisfaction with future pUAM in these dimensions will differ amongst a population. Drawing on the literature, a broader satisfaction with pUAM in society could be achieved when aiming for a high safety perception, e.g., having a pilot on board (cf. [64]) and a pricing policy of around EUR 2 per kilometre and passenger (cf. [67]) while stable operation (cf. [68]) and travel time saving is ensured (cf. [55]). Nevertheless, early business models must be anticipated to follow demand-driven approaches. Based on the reviewed studies, the target group usually contains a high share of younger, technophile males with higher education and income, living and frequently commuting individually in FUAs [11,37,59,60,64]. Consequently, satisfaction with the urban transportation system would only improve for this subgroup, while the majority of citizen will not feel considered.

From the existing literature regarding the **impact of UAM on the quality of public spaces** it appears relevant to anticipate a negative impact of eVTOLs and infrastructure on citizens' perception towards the quality of urban public spaces. This impact might initially be smaller due to low traffic density. However, external traffic costs such as noise and stress for residents in the vicinity of vertiports and along corresponding flight corridors should be highlighted when operation increases. Aesthetic demands for a clear urban sky, e.g., in recreational areas are suggested to play a significant role in connection to a high sojourn quality. Privacy and safety concerns might additionally influence how citizens perceive public spaces in which numerus aircrafts are deployed [70]. If or to what extent the quality of public spaces deteriorates may depend on the balancing between economic interests for a permissive airspace usage on the one hand and citizen-focused governance on U-Space and vertiport planning on the other hand. From the point of analysis, it is seen as favourable if municipal and regional planning authorities become key decision makers regarding the configuration of their urban airspace to mitigate conflicting interests between different stakeholders on the local level. Besides a corresponding legal framework, however, urban planning competences would have to be strengthened and participatory procedures developed (cf. [4]). In support of this, urban planning, sociology and human geographic perspectives must be embraced in the sustainable development of urban airspace and its ground infrastructure components [77].

6. Conclusions

The first step to steer passenger Urban Air Mobility (pUAM) towards the goal of sustainable mobility is to better understand the impact of its introduction on our urban transportation systems. This analysis focused on the prospective impact of pUAM on the five dimensions of socially sustainable urban transportation as adopted from the Sustainable Urban Mobility Indicators (SUMI) framework. Overall, it is to conclude that the introduction of pUAM will have a rather negative impact on the social sustainability assessment of European urban mobility systems. The short- to mid-term affordability of pUAM for broad parts of the population cannot be expected without public subsidies. For this engagement, however, local community must first demand clear prospects for added value. Similarly, the overall inclusivity evaluation of urban transportation systems must be expected to decline if planning authorities will not demand certain standards for mobility-impaired groups. Vertiport operation in already developed urban locations might not improve accessibility, however, cross-financed and open access mobility hubs in suburbs and rural areas might include pUAM and thus contribute positively to the access indicator. A high level of satisfaction with pUAM among the public is not expected due to target-group specific business modelling. Last but not least, an impairment of the overall quality of urban public spaces is likely but might be minimised through the allocation of legal competences for urban airspace planning and civil society participation on the local level.

Limitations: Due to the upsurge of literature on UAM and the selection of only two databases, it may not have been possible to include all contributions in the field of research. Nevertheless, a consistent picture of prospective planning requirements should have been drafted. Further, while a share of the cited literature in this analysis emphasises futuristic on-demand operation of autonomous air taxis, the frame of analysis in this research was on early market, scheduled operation in European functionally urban areas. Thus, the transferability of results may have been prone to errors. Finally, the results of this study remain on a conceptual level. A future technology assessment in the presented categories should be conducted as local case studies, factoring in the regional specifics, vehicle characteristics and operational model.

Relevance and outlook: The expansion of metropolitan transportation to low-level airspace seems pending. It is predictable that attractive European metropolitan areas will be confronted with business concepts as soon as the legal framework will allow. However, in analogy to the paradigm of sustainable urban development, the deployment of passenger Urban Air Mobility should follow a holistic approach from the start. For political stakeholders on the regional and local level, a forward-looking understanding on the opportunities and risks associated with the new mobility offer will be key in making confident decisions regarding an introduction. For planners, it becomes apparent that new competencies and creative solutions will be required to steer urban air mobility towards sustainable mobility for the common good. Chiefly, this challenge calls for the active engagement of civil society, as without stakeholder participation there is not only a risk of a societal rejection and division, but also of decisions being made that do not realise positive innovation potentials of this technology.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Acknowledgments: I acknowledge support by the German Research Foundation and the Open Access Publication Fund of TU Berlin.

Conflicts of Interest: The author declares no conflict of interest.

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Air Transport Centrality as a Driver of Sustainable Regional Growth: A Case of Vietnam

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Abstract: With fast-growing aviation markets, many developing countries are showing remarkable economic development in global terms. As significant growth of air transportation is crucially interrelated with regional growth, it is essential to identify relevant criteria to ensure effective allocation of investments in this regard. This study aimed to investigate airport centrality using social network analysis to detect the key hubs and examine the interrelationship between airport centrality and regional economy indicators in Vietnamese regions. The results revealed that the cities of Tan Son Nhat, Noi Bai, and Da Nang were the key regional hub airports in the air transport network and the development of these leading cities had played a significant role in promoting the improvement of the entire domestic air network. Moreover, the results showed a strong positive correlation between airport centrality and regional growth features. Therefore, policymakers can optimize their decision-making processes in relation to sustainable regional development by considering air transport mobility and network in addition to conventional socioeconomic criteria.

Keywords: airport; centrality; social network analysis; regional growth indicator; Vietnam

Citation: Trinh, T.A.; Seo, D.; Kim, U.; Phan, T.N.Q.; Nguyen, T.H.H. Air Transport Centrality as a Driver of Sustainable Regional Growth: A Case of Vietnam. *Sustainability* **2022**, *14*, 9746. https://doi.org/10.3390/su14159746

Academic Editor: Lynnette Dray

Received: 24 June 2022
Accepted: 5 August 2022
Published: 8 August 2022

1. Introduction

The selection of regions to develop needs careful consideration due to a shortage of government resources, especially in developing countries. Many factors have been considered in the process of allocating resources for regions, such as regional product per capita, population size, and population density [1], preference in terms of efficiency for productive regions or equity for disadvantaged regions [2], and political factors [3]. Generally, central governments focus their investments in areas with higher growth potential [4]. Overall, political and regional economic indicators are primarily considered. However, transportation plays a critical role in promoting economic growth [5] and can create a competitive advantage for the concerned region. Identifying relevant traffic-related indicators is likely to be helpful in selecting geographic areas as a development priority to promote regional growth and increase the efficiency of public investment.

According to Oh et al. [6], Vietnam's transport infrastructure includes roads, railways, inland waterways, maritime, and airways. The country has about 30,900 km of road length, including 2130 nodes and 20,512 links connecting all 63 provinces. The maritime network is the second largest logistics network in freight transport after the road system. The waterway system is a regional network locating separately in the two regions of the Red River Delta (in the North) and the Mekong River Delta (in the South). The railway system does not connect all provinces but links the two north–south dynamic cities, Hanoi and Ho Chi Minh City. The outdated railway system and single-track technology limits railway accessibility. The air transport network includes 23 airports scattered throughout the country. The three major aviation hubs (international airport and service volume) are situated in the country's northern, central, and southern regions. The share of air transport of the total cargo transported in Vietnam is rapidly increasing. Few studies [7,8] affirm the role of transport modes, especially air transport, in promoting tourism and economic growth. Yu and Luu [9] state that investment in transport infrastructure in Vietnam can increase the employment rate across industries. In addition, developing transport infrastructure can improve the connection between the regional and national economies. This suggests the role of transportation infrastructure network and its connectivity on regional/national development.

The relationship between airports and economic development has long been a topic of interest in research. Various studies have demonstrated the active role of airports in regional economic development [5,10–12]. Further, some studies have shown the positive impact of regional development on the growth of passenger numbers and cargo traffic through regional airport [13,14], and other studies have highlighted a significant bidirectional relationship between having an airport and regional growth [15–17]. Pot and Kosster [18] affirm the major impact of large airports in regional economy compared to that of small airports. Therefore, it seems plausible that using airport centrality as an indicator to select an area for resource development is likely to help increase the efficiency of investments.

Within Southeast Asia, Vietnam has recently led with a precipitous growth at 3.6 times from 2002 to 2021 [19], with a remarkable surge in foreign direct investment (FDI), stimulating economic development [20]. The middle class in Vietnam—people who earn an average monthly income of at least 15 million Vietnam dong—is growing faster than other Southeast Asian regions [21]. As the national economy grows and many cities become developed through rapid urbanization and industrialization, the annual amount of logistical engagement between cities has been increasing. In particular, Vietnam has become one of the fastest growing aviation markets in the world following the recent surge in domestic and foreign tourism industries [22]. Geographically, Vietnam is characterized as narrow in east–west terms and long, at approximately 1650 km, in north–south terms. However, the surface transportation system and railway infrastructure are no longer adequate, but new developments in related infrastructure have not been implemented. The aging railway system and its trains cause long travel times. Although a high-speed train network has been under discussion for the last decade, no further development has occurred [23]. The projected 1st National Highway from Ho Chi Minh City to Hanoi, which is intended to link most provinces, has been delayed for several decades, with only a few sections under construction and other sections facing various issues such as lack of investment and delayed compensation [24]. Consequently, Vietnam's aviation industry is now growing at a tremendous yearly rate of 16%, twice as fast as Asia's average aviation market growth, and the size of the market is expected to reach 785 billion US dollars in 2038 [25]. However, despite being declared as one of the fastest recovering countries from the COVID-19 pandemic [26], the supply chain disruption owing to the pandemic has affected the Vietnam air transport market significantly. In 2020, Vietnam's air transport market witnessed a revenue drop by about 4.35 billion USD compared to 2019. The Civil Aviation Administration of Vietnam has re-evaluated the market outlook. The passenger and cargo growth are 7.5–8.5% and 8.4–9.7%, respectively [27]. This shows that Vietnam's aviation market still displays great prospects for the future. Despite the significant growth in air transportation and its essential role in regional growth, investment decisions for regional development are still far from the existence of airports in the region. Traditional approaches prefer using traffic statistics. However, constructing a macrolevel criterion based on aggregate microinformation at the individual passenger level seems costly (both time and money). The detailed, diverse, and fragmentary information is a major obstacle in describing a general picture. Here, the connection among airports has the advantage of ease of observation. Therefore, we considered airport connection over the centrality approach as it is easier to observe, more superficial, and more generalized.

In seeking to understand the relationship between airport infrastructure and regional development, this study aimed to (1) investigate airport centrality using social network analysis (SNA) to detect the key hubs of Vietnamese regions and (2) examine the interrelationship between airport centrality and regional economy indicators. Research concerning Vietnamese airports has rarely investigated matters such as connectivity and centrality, despite the remarkable and ever-increasing rate of national economic growth particularly in relation to the extensive development of air transportation infrastructure and networks. Therefore, this study provided relevant and evidence-based recommendations concerning what needs to be prioritized for effective national resource allocation and redistribution, based on the results of airport centrality analysis. Furthermore, this study identified a key indicator, namely airport centrality, for consideration when selecting potential development areas for regional economic growth.

This study is organized as follows: Section 1 introduces research backgrounds, purposes, and the structure of this study. Section 2 includes a theoretical review of the relationship between airport connection and regional economy, regional centrality, and empirical studies of airport centrality. Section 3 discusses research methods such as data collection, rearrangement, analysis modeling, and procedures. Section 4 presents analysis results of centrality and correlations, findings, and discussions of airport centrality as a driver of sustainable regional growth. Finally, Section 5 concludes the study by including a summary of key findings and their implications, study limitations, and further research directions.

2. Literature Review

2.1. The Interactive Relationship between an Airport and the Regional Economy

The transportation infrastructure of a country is one of the most important indicators of its economic growth [28]. Airports are often located in densely populated areas in which there are many industries, leading to high volumes of products and greater travel needs [11]. Debates concerning the interaction between infrastructure supply and economic productivity at regional and national levels are ongoing, with important implications for public decision-making [10,11,13,14,27,29]. Aschauer and Alan [29] have shown the correlation between transport infrastructure and productivity growth at the national level. Airports influence the growth of a region through allowing faster and greater volumes of passenger and cargo flows and improving economic output per capita. The larger an airport, the stronger its effect [11]. Air transport services lead to a statistically significant increase in economic growth in the regions [10]. Similarly, using Granger causality testing, Button and Yuan [12] confirmed a causal relationship between air transport as a positive driver and local economic development after conducting a data analysis of 35 airports in 32 metropolitan areas in the United States. In contrast, certain other features such as gross regional domestic product (GRDP), economic decision-making power, tourist characteristics, and the distance to a large aviation hub have been proposed as deciding factors for air traffic volume [13]. Besides, Fernandes and Pacheco [14] claimed there was a causal relationship between the economic growth and demand for domestic air transport in Brazil.

Airports are among the core infrastructures that explain the effect on productivity [30]. Allroggen and Malina [31] refer to the requirement of a synchronous investment to enrich "core connectivity" in the airport system to achieve economic growth. In addition, investing in airports is a way for policymakers to make the region more attractive to investors. Sheard [32] deals with the impact of airport infrastructure on labor and employment. Thus, airports at different levels can become indicators of economic development potential in different ways. Given that investigations have found the two-way relationship between air transport and economic growth to be generally positive, airports are viewed as vital infrastructure not only for the economy but also for local governments promoting regional development. There is an awareness that funding needs to be attracted for targeted airports to support growth [15]. It has been claimed that a two-way relationship between air transport and the economy is more evident in developing countries, whereas a one-way relationship between air transport and economic growth is more apparent in developed countries [17]. Mukkala and Tervo [16] found a causal relationship between regional growth and air traffic, especially in remote areas, that led to subsidies to local airports in those regions. There seems to be sufficient evidence to indicate that there is a relationship between the distribution of an air transport network and economic activities. Moreover, Jia, Quin, and Shan [33] found that an airport network had a significant impact on stimulating notable regional economic growth after conducting an exploratory analysis on airport networks from 1990 to 2010. Therefore, it appears that consideration of the characteristics of an airport network is likely to be of value for policymakers across multiple domains beyond purely research. Specifically, assessing the key locational factors affecting regional airports within the national air transport network is essential in understanding how the development of economic activities regionally can be undertaken more effectively.

An aviation connectivity report by IATA [34] (p. 12) stated, "Air connectivity generates benefits for local and national economies, including improved competitiveness and enhanced employment and economic growth opportunities." This report also refers to their previous research with Inter VISTAS and Oxford Economics that showed a 10% increase in air connectivity boosts labor productivity by about 0.07% and creates a 1.1% GDP increase in the long run [34]. Bel and Fageda [35] concluded that a 10% increase in new international routes could increase the number of large corporate headquarters by 4%, especially those with intensive knowledge, thus contributing to urban economic development. The study concluded that policies to attract companies should accompany the investment in developing international flights. Moreover, the presence of new flight routes, that is, increased airport connections, witnessed an increase in FDI inflows [36]. Bilotkach [37] asserts that, in addition to traffic flow, the number of destinations creates the most obvious influence on employment, the number of new businesses, and the level of regional average salary. Discussions on air connectivity promote orientations toward the role of airports and their connection with regional development and emphasize the attention to the connection level of the airport with regional economic development indicators.

2.2. Airport Centrality Measurement as an Indicator of Economic Growth

A busy airport is often the driving force of the economy, as it promotes other airports to thrive through connected networks and boosts the country's economy [38]. Chen and Lee [39] measured the degree centrality, betweenness centrality, and closeness centrality of 10 major airports in Southeast Asia and concluded that urban interactions could benefit from reducing the complexity of airport networks. Airport centrality is commonly measured by degree, betweenness, and closeness centrality using SNA [40–42].

SNA was first introduced by Moreno [43]. It is applied to increase the understanding of the complexity of systems, such as that of a transport network [44]. It provides a capability to analyze connections in a transport network, which shares some fundamental characteristics with social networks. In addition to the fields of physics, data science, computational linguistics, epidemiology, fashion, information exchange, and marketing [44], SNA has been applied in transport planning and economics since the 1930s [45]. Furthermore, SNA is more cost-effective than traditional traffic network analysis as it does not require the fulfillment of stringent data requirements but can still deliver reliable results [46]. Furthermore, compared to standard analysis methods that focus heavily on individual attributes, SNA examines and evaluates individual attributes in the context of overall network relationships [44].

In applying SNA in this study, degree centrality is used in reference to a large-scale or busy airport, betweenness centrality refers to the influence of an airport in terms of its intermediary role, and closeness centrality refers to an airport that is closest to the remaining nodes. Finally, Bonacich beta (β) centrality illustrates how well an airport connects to the more significant nodes. Besides discovering important nodes to improve the network, the high-centrality nodes boost tourism in the country [47]. Sapre and Parekh [47] further emphasize the role of the city's centrality in the spatial description of economic activities. Note that this study calculates the city center values by air connections. Some studies [48,49] show a strong correlation between socioeconomic indicators and centrality values. These studies calculated the central nodes in a transportation system to specify the indicative relationships for regional development. Their findings indicated that it was not necessary for a hub airport to have very high centrality values, as some airports were found to have notably high centrality, whereas others did not. Airports with high centrality would be expected to become hubs as they trigger flight routes and act as connectors to other airports. Generally, results of investigations showing consistent high centrality indicators for hub airports suggest that SNA can be a valuable tool for analysis.

Further analysis of the relationship between airport centrality indexes and other socioeconomic variables and airport characteristics has been conducted. The approach by Wang, Mo, Wang, and Jin [48] to analyze the centrality of an airport network established a high correlation between the three centrality indicators and air passenger volume, population, and GRDP. The central nodal positions of the airports identified in their study were explained in terms of economic power, tourist attractions, and the advantages of central geographic locations for connecting flights. These findings further support an airport's central role in the spatial formation of economic activities and the usefulness of SNA in determining the key transportation hubs within specific and important geographical locations.

Hence, airport centrality appears likely to be useful as a potential indicator of areas with significant economic development potential, while SNA appears to be an appropriate analytical method for determining the critical nodes in a transport network.

3. Research Methods

3.1. Data Collection and Rearrangement

As traffic volume was considered to meet the requirements of SNA in the context of a transport network, this study used data concerning the number of domestic air passengers who travelled through 20 Vietnamese airports located across the country. To analyze airport centrality rank fluctuations, passenger origin–destination (O–D) datasets for 5 years (2014–2018) were obtained with the support of the Civil Aviation Authority of Vietnam. The relevant panel data included the number of passengers on each route for the study period. Then, the data were reorganized using a three-dimensional matrix structure. The number of passengers present at 20 domestic airports in Vietnam over the 5-year period was symmetrized using the MAX method with UCINET 6 after switching to the O–D matrix. This was used to reconstruct the data because aviation O–D data provided a useful indicator in defining regional centrality and relevant networks. As this matrix contains information concerning the air traffic between regions, it can readily estimate traffic volume in the network [50]. In addition, other regional data were sourced from the General Statistics Office of Vietnam (https://www.gso.gov.vn, accessed on 7 September 2020) in the years corresponding to the transport data.

3.2. Analytical Framework

Centrality concepts used in SNA discover important network actors and evaluate the impact of network structure and surrounding factors on the changes in nodes' importance [51]. Centrality values commonly used in studies include degree centrality, which considers agents with more interactions as superior [52,53] and eigenvector centrality, which favors agents connected to many influential nodes. Degree centrality indicates the number of direct connections, whereas eigenvector centrality emphasizes the relationship governed by weights. According to the literature [54], Bonacich β centrality is a generalization of degree centrality and eigenvector centrality. For Bonacich β centrality, direct and indirect connections are essential [55]. The β can adopt either positive or negative values. When β is negative, the network actors are mutually influenced but competitively. Conversely, a positive value of β indicates that the network is complementary.

This study calculated the annual centrality values of all of Vietnam's operating airports according to degree centrality and Bonacich β centrality. Degree centrality represents the linkage power among actors [56]. Actors with a positional advantage have many alternatives to meet the needs of other actors and are less dependent on other actors around them. If centrality is defined as a pathway, there are both opportunities and risks involved in terms of exposure to whatever flows through the network [57]. In this study, degree centrality was determined in relation to air traffic volume. Airports with high degree centrality have high power compared to other airports. The following degree centrality formula was used [57]:

$$C_D(N_i) = \sum_{j=1}^{g} R_{ij},\ i \neq j \quad (1)$$

where

$C_D(N_i)$: i degree centrality of airport;

g: number of airports;

$\sum_{j=1}^{g} R_{ij}$: number of connections between airport i with $(g-1)$ other airports.

Bonacich β centrality is an indicator used to identify and reflect the overall nature of the network comprising all the actors that focuses on measuring the centrality index of each node or actor. Bonacich [58] clarified that the power of an actor comes not only from the actors close to that actor but also from actors further away and is ultimately determined within the entire network structure. This is advantageous in that "the Eigenvector and Bonacich power methods explain how nodes play an important role in a social network structure and how such a node has a higher power in the network" [44]. The formula used for Bonacich β centrality was as follows:

$$c_i(\alpha,\ \beta) = \sum_{j}^{g} (\alpha + \beta c_j) R_{ij} \quad (2)$$

where

c_i: β centrality columns of the actor;

α: parameter to standardize the centrality;

β: weighted parameter based on traffic volume from the actor;

R_{ij}; adjacent matrix with R_{ij} as element.

The calculation of the two centrality measures extended the depth and complexity of the analysis. The more the indicators pointing toward an actor, the more likely the actor is accurately identified as a central node. Data on annual changes in the centrality ranking of airports need to be recorded to ensure consistency when using SNA. If one or some nodal hubs clearly do not shift in ranking over the selected time, SNA can be considered reliable. Meanwhile, any centrality shift also indicates that one airport has a high-volume traffic compared to other nodes, implying a relatively stronger inner dynamic in certain areas. Furthermore, the correlation between the centrality indicators and the key regional variables of population density and GRDP was analyzed to assess the plausibility of using centrality analysis in relation to regional growth.

3.3. Data Analysis

Using UCINET 6, this study calculated nodal centrality by deriving degree centrality and Bonacich β centrality. The mean values of internal and external degrees were used for degree centrality at each airport to select representative values for the degree of connection at each airport. To identify network characteristics, Pearson correlation was calculated using R programming. We observed that the airport network in Vietnam had complementary connections, so the β value was taken as 1/max eigenvalue. This study identified the network relationships and characteristics of each airport with its surrounding airports. Based on all the airport networks in Vietnam, centrality between 2014 and 2018 was analyzed to determine the reasons for each selected airport's growth, decline, and change in centrality.

4. Findings and Discussions

4.1. Degree Centrality

The results indicated that the three leading airports were Tan Son Nhat (1st), Noi Bai (2nd), and Da Nang (3rd), while the three least important airports were Dien Bien (19th), Con Dao (18th), and Tuy Hoa (17th) in 2018 (Table 1). In terms of degree centralities, Tan Son Nhat, Noi Bai, and Da Nang were shown to have many routes to other airports in the domestic network and carried the largest volume of air traffic. Notably, these airports remained the leading airports in terms of connectivity over the 5 years. All three airports are in major cities, namely Ho Chi Minh City, Hanoi, and Da Nang, respectively. Hanoi and Ho Chi Minh City are the major economic hubs in the north and south, respectively, while Da Nang is the major economic and tourism hub in central Vietnam.

Table 1. Degree centrality and rank of each airport in Vietnam.

Airport	2014		2015		2016		2017		2018		2014–2018	
	Centrality	Rank	Centrality	Rank	Centrality	Rank	Centrality	Rank	Centrality	Rank	Centrality Change	Rank Change
Tan Son Nhat	6,459,327	1	4,531,344	1	6,444,682	1	11,012,848	1	11,519,483	1	5,060,156	0
Noi Bai	4,302,185	2	2,527,916	2	3,580,582	2	7,446,083	2	7,914,024	2	3,611,840	0
Da Nang	1,985,482	3	1,252,799	3	1,629,011	3	3,450,339.5	3	3,535,767	3	1,550,285	0
Cam Ranh	724,533.5	4	369,982	6	620,540.5	5	1,313,413	4	1,435,516	4	710,982	0
Phu Quoc	486,557.5	7	394,081	5	620,647.5	4	1,193,770.5	5	1,329,164	5	842,606.5	−2
Phu Bai	573,761.5	5	283,550.5	8	394,840	8	846,411.5	6	892,827	7	319,065.5	2
Cat Bi	464,808	8	410,472.5	4	585,827	6	834,299.5	7	955,200	6	490,392	−2
Vinh	535,428	6	363,863.5	7	520,689.5	7	780,170.5	8	774,976	8	239,548	2
Lien Khuong	298,806	10	185,369.5	11	365,107	9	610,637	9	605,597.5	9	306,791.5	−1
Phu Cat	209,674.5	11	149,672	12	308,799	11	555,924.5	10	595,432	10	385,757.5	−1
Tho Xuan	82,298	15	216,731.5	9	314,662	10	392,621	12	434,296.5	11	351,998.5	−4
Chu Lai	20,340.5	19	62,142	15	272,599.5	13	337,538	13	362,373.5	13	342,033	−6
Buon Ma Thuot	308,288.5	9	195,434.5	10	280,519.5	12	407,541.5	11	410,785	12	102,496.5	3
Pleiku	150,358	12	37,406	18	206,803.5	14	319,155.5	14	320,190.5	14	169,832.5	2
Can Tho	138,593.5	13	58,961	16	83,842.5	18	253,126.5	15	290,890	15	152,296.5	2
Dong Hoi	58,734.5	16	77,799	14	130,349.5	16	217,623.5	16	261,184	16	202,449.5	0
Tuy Hoa	32,098.5	18	38,442.5	17	164,155	15	167,341	17	194,061	17	161,962.5	−1
Con Dao	93,639	14	104,198.5	13	112,053	17	137,430	18	164,433	18	70,794	4
Dien Bien	40,630	17	0	20	31,526	19	32,999.5	19	23,320.5	19	−17,309.5	2
Ca Mau	15,219	20	13,841	19	15,257.5	20	15,183.5	20	16,146.5	20	927.5	0

In contrast to those stable rankings, Chu Lai and Tho Xuan airports had significant shifts in rank, going from 19th to 13th place and from 15th to 11th place, respectively (Figure 1). Chu Lai and Tho Xuan operate only domestic flights, despite Chu Lai being an international airport, with Chu Lai airport having only two routes to Tan Son Nhat (1st) and Noi Bai (2nd) and Tho Xuan having only one route to Tan Son Nhat. These changes in rankings showed that the air traffic growth rates of these airports had been higher than those of other domestic airports over the same period, with Chu Lai airport leading in terms of growth with 28 times more traffic, and with Tho Xuan airport lying second with a fivefold traffic increase across 5 years. Can Tho ranked 13th in 2014 but dropped to 15th in 2018. The closure of the Phu Quoc route caused Can Tho to reduce its operation from three connections in 2014 to two connections in 2018. Furthermore, despite being connected (as was the case with Tho Xuan) to Tan Son Nhat, Ca Mau airport continued to rank the lowest in terms of traffic growth at 20th over 5 years, lower than Chu Lai (19th), Tuy Hoa (18th), and Dien Bien (17th). No notable changes occurred in relation to the other airports.

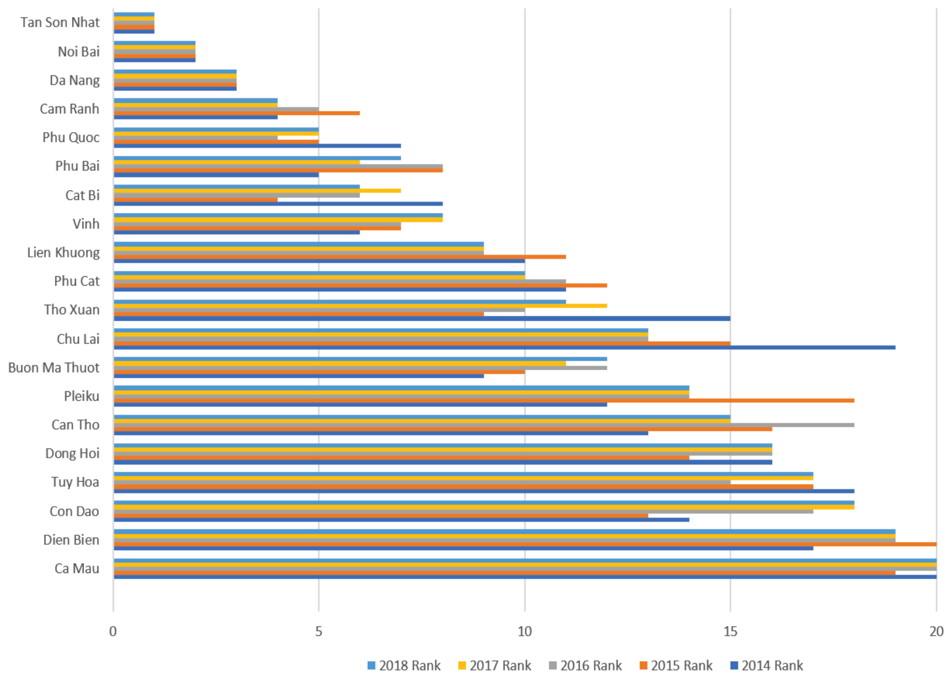

Figure 1. Degree centrality rank change of each airport in Vietnam.

4.2. Bonacich Beta Centrality

Bonacich centrality values concern the extent of associations within well-connected nodes, with a node having higher centrality when connected to a greater number of other central nodes. As Tan Son Nhat and Noi Bai were the most central airports (Table 2), other airports obtained higher scores if they were connected to these airports. All the airports had at least one connection to the three hub airports of Tan Son Nhat, Da Nang, and Noi Bai as at the end of 2018, apart from Rach Gia, Na San, and Van Don. Connections with major airports had a positive effect, as shown in terms of degree centrality (Figure 2). The two almost identical centrality rankings across 5 years indicate the leverage roles played by the three hub airports (Figures 1 and 2).

4.3. The Relationship between Centrality Indicators and Regional Growth Indicators

Degree centrality depends on traffic volume transfer among nodes, which is related to the number of routes at each airport and the traffic on each route. The more extensive the number of routes and the greater the traffic, the higher the Bonacich β centrality. As expected, the leading airports operated a large number of routes, with Tan Son Nhat operating the largest number of domestic routes (17 routes), followed by Noi Bai (15 routes).

However, this type of understanding appeared to be inadequate in explaining the change in ranking regarding several airports. When comparing changes between 2014 and 2018, we observed that Tho Xuan maintained only one connection with Tan Son Nhat, and Chu Lai still had only two connections with Tan Son Nhat and Noi Bai, whereas Phu Quoc reduced one connection with Can Tho and kept only two linkages with Tan Son Nhat and Noi Bai. Therefore, the number of connecting points could not satisfactorily explain the rise in centrality ranking for these airports, raising the question as to what caused the increase in traffic volume between certain node pairs (Chu Lai–Tan Son Nhat, Tho Xuan–Tan Son Nhat, and Phu Quoc–Tan Son Nhat). The answer appears to be a rise in traffic volume on existing connections. As discussed, the regional economy can be viewed as a major driver of air travel demand. In addition, the aviation demand forecasting sector is well aware of the significance of population density, with more people increasing the potential travel demand. Therefore, this study assessed the correlation between the centrality measurements and GRDP values as well as population density. Figure 3 indicates the mapping of centrality results of each airport with population and GRDP of each province.

Table 2. Bonacich beta (positive) centrality and rank of each airport in Vietnam.

Airport	2014		2015		2016		2017		2018		2014–2018	
	Centrality	Rank	Centrality	Rank	Centrality	Rank	Centrality	Rank	Centrality	Rank	Centrality Change	Rank Change
Tan Son Nhat	6,459,327	1	4,531,344	1	6,444,682	1	11,012,848	1	11,519,483	1	5,060,156	0
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Cam Ranh	724,533.5	4	369,982	6	620,540.5	5	1,313,413	4	1,435,516	4	710,982	0
Phu Quoc	486,557.5	7	394,081	5	620,647.5	4	1,193,770.5	5	1,329,164	5	842,606.5	−2
Phu Bai	573,761.5	5	283,550.5	8	394,840	8	846,411.5	6	892,827	7	319,065.5	2
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Chu Lai	20,340.5	19	62,142	15	272,599.5	13	337,538	13	362,373.5	13	342,033	−6
Buon Ma Thuot	308,288.5	9	195,434.5	10	280,519.5	12	407,541.5	11	410,785	12	102,496.5	3
Pleiku	150,358	12	37,406	18	206,803.5	14	319,155.5	14	320,190.5	14	169,832.5	2
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Dong Hoi	58,734.5	16	77,799	14	130,349.5	16	217,623.5	16	261,184	16	202,449.5	0
Tuy Hoa	32,098.5	18	38,442.5	17	164,155	15	167,341	17	194,061	17	161,962.5	−1
Con Dao	93,639	14	104,198.5	13	112,053	17	137,430	18	164,433	18	70,794	4
Dien Bien	40,630	17	0	20	31,526	19	32,999.5	19	23,320.5	19	−17,309.5	2
Ca Mau	15,219	20	13,841	19	15,257.5	20	15,183.5	20	16,146.5	20	927.5	0

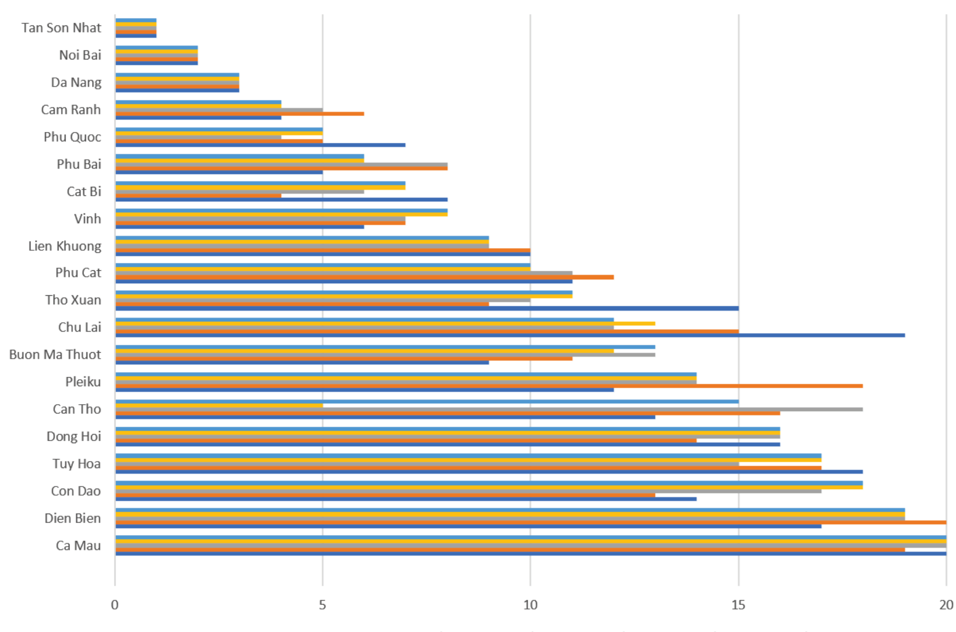

Figure 2. Bonacich (positive) centrality rank change of each airport in Vietnam.

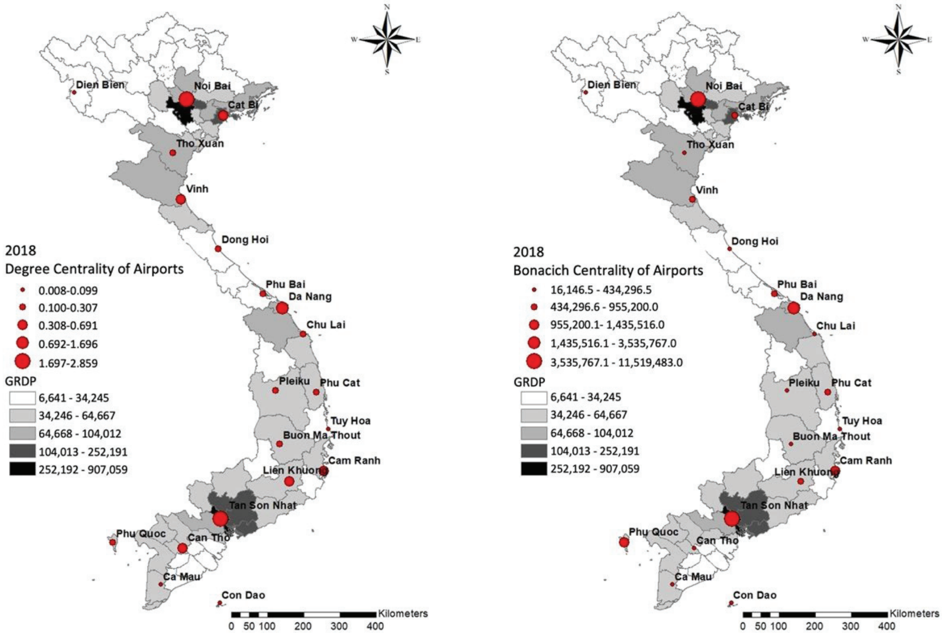

Figure 3. Mapping of centrality results of each airport with population and GRDP in 2018.

The results of the correlation tests shown in Table 3 depict a strong correlation between population density and GRDP and both centrality indicators. This also indicates a clear positive relationship between population density and economic development of an area, such as FDI, industrial products, enterprise, employment, and tourism, in relation to airport centrality.

Table 3. The correlation analysis among centralities and regional growth indicators.

	Degree Centrality	Bonacich Centrality	Population	GRDP	FDI	Industrial Product	Enterprise	Employment	Tourism
Degree Centrality	1								
Bonacich Centrality	0.960 **	1							
Population	0.901 **	0.841 **	1						
GDRP	0.965 **	0.917 **	0.961 **	1					
FDI	0.827 **	0.773 **	0.850 **	0.932 **	1				
Industrial Product	(−)0.095	(−)0.064	00.139	(−)0.076	00.139	1			
Enterprise	0.977 **	0.905 **	0.938 **	0.973 **	0.887 **	(−)0.056	1		
Employment	0.868 **	0.805 **	0.995 **	0.905 **	0.883 **	(−)0.203	0.909 **	1	
Tourism	0.952 **	0.850 **	0.876 **	0.919 **	0.848 **	(−)0.093	0.978 **	0.805 **	1

Note: ** Correlation is significant at the 0.01 level (2-tailed).

Tho Xuan retained its connection only with Tan Son Nhat, as well as the strength of the Tan Son Nhat node, indicating that attention should be paid to the relationship between Tan Son Nhat and Tho Xuan. The GRDP of Thanh Hoa (Tho Xuan airport) is more than 2.5 times more than that of Ca Mau and 9 times more than Dien Bien [59]. Excluding Ho Chi Minh City, Ha Noi, and Hai Phong, Thanh Hoa is a leading city in terms of GRDP and population. This factor is likely the reason for Tho Xuan showing a remarkable change in its ranking importance, whereas Ca Mau and Dien Bien had low centrality values and maintained their lower rankings over the years, despite Tho Xuan operating only one route to one of the two major airports in Hanoi and Ho Chi Minh City. Moreover, although most airports were connected to the three busiest airports, Tho Xuan consistently improved its score across all three centrality indicators. These findings highlight the importance of considering passenger transfer flows between nodes in terms of population density and economic development factors. In relation to Chu Lai, Quang Nam is a province with a substantially higher GRDP and population density with economic growth factors compared to other provinces. This explained why Chu Lai showed a remarkable rise in centrality rankings, while Tuy Hoa, Phu Cat, Dong Hoi, and Vinh showed no significant changes, although Chu Lai only operated two routes to Tan Son Nhat and Noi Bai. This suggests that an airport can promote its central role in terms of positively increasing traffic volume and airline service usage because of the advantages deriving from high local population density and regional development.

5. Conclusions

This study investigated whether an air transport node in terms of its centrality could be an important indicator of where economic development needs to be better integrated with key transport infrastructures. Using centrality analysis based on O–D data concerning domestic air traffic in Vietnam from to 2014 to 2018, the following conclusions were derived.

First, SNA was found to be a reliable method in identifying the three most central airports of the domestic air traffic network in Vietnam, namely Tan Son Nhat, Noi Bai, and Da Nang, over the study period of 5 years, using centrality measurements. The consistent results in terms of the leading positions retained by these airports can be explained through their locations in the three most important economic centers and tourist hubs of Vietnam. As Vietnam's aviation industry continues to develop, aviation O–D data and SNA methods can provide key information to effectively identify not only airport centrality but also city centrality. Although India's airport network analysis depicts that airports with high centrality scores are not necessarily the ones with the highest traffic volume or the closest distances to other airports [47], the other two studies support this study's results [40,48]. The assessment of the airport network in Australia shows the high centrality of the three major Australian airports—Sydney, Brisbane, and Melbourne [40]. This outcome is similar to the study of the airport network in China, which is consistent with the network in emerging countries. The centrality approach also delivers the outstanding rankings of the three largest Chinese airports, namely Beijing, Shanghai, and Guangzhou [48]. Second, the airport network in Vietnam was found to be a reciprocal system, meaning that the actors in the system tended to operate collaboratively rather than competitively. The Vietnamese aviation industry has grown extensively—not only in certain airports over a study period of 5 years but also overall—because of the benefits deriving from the three network leaders, Tan Son Nhat, Noi Bai, and Da Nang, promoting improvement throughout the domestic network. This finding corroborates that of a recent study of air transport in Vietnam [60]. Hub airports, as Saleena et al. [38] state, are engines of economic growth because they control routes to spoke airports and generate increasing traffic flows. Third, this study clarified the relationship between air transport mobility and regional characteristics. Airports in areas of high-density population and economic development values were highly ranked and retained their rankings. Economic and residential spatial organization were linked to the spatial distribution of important airports in the national aviation network. Notably, in terms of improving rankings for certain airports, these factors need to be considered in terms of future investment because there is a " … burgeoning demand between Tier Two cities" [60]. Cátells and Sole'-Olles [3] demonstrated the relationship between the distribution of infrastructure investment by region, emphasizing the influence of population, regional product per capita and primary and secondary sectors, and other political factors. This study reckons that localities with stable high-ranking airports are those with large populations, strong regional economies, and prioritized public investment allocation. Therefore, policymakers can optimize their decision-making processes in relation to sustainable regional development by considering air transport mobility and network in addition to conventional socioeconomic criteria.

A limitation of this study is that it analyzes only passenger flow data, but the flow of goods may also be meaningful in understanding the dynamic growth of airports and its influence on socioeconomic factors. Therefore, future studies can include more dynamic networks by integrating logistical information concerning the flow of goods, as well as passenger flows, so that regional economic development can also be influenced through greater awareness of such diverse types of information.

Author Contributions: Conceptualization, T.A.T. and D.S.; data curation, T.A.T. and T.H.H.N.; formal analysis, D.S. and U.K.; investigation, D.S. and U.K.; methodology, D.S. and U.K.; project administration, D.S.; resources, T.A.T. and T.H.H.N.; software, U.K.; supervision, T.A.T. and D.S.; validation, D.S.; visualization, D.S. and U.K.; writing—original draft preparation, U.K. and T.N.Q.P.; writing—review and editing, T.A.T., T.H.H.N., T.N.Q.P. and D.S. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2022R1G1A1006825).

Institutional Review Board Statement: Ethnical review and approval were waived for this study, as the research was conducted using information available to the general public and not collecting personal identification information.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The socio-economic data of Vietnam are publicly available from the General Statistics Office of Vietnam, https://www.gso.gov.vn/en/homepage/.

Conflicts of Interest: There are no conflict of interest to declare.

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