Integrating ATM and air transport into multimodal transport system for Door-to-Door travel: the X-TEAM D2D project proposed approach

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Abstract. The project X-TEAM D2D (Extended ATM for Door-to-Door Travel) has been funded by SESAR JU in 2020 and completed its activities in 2022, pursuing and accomplishing the definition, development and initial assessment of a Concept of Operations (ConOps) for the seamless integration of ATM and air transport into an overall intermodal network, including other available transportation means (surface, water), to support the door-to-door connectivity, in up to 4 hours, between any location in Europe. The project addressed the ATM and air transport, including Urban Air Mobility (UAM), integration in the overall transport network serving urban and extended urban (up to regional level) mobility, specifically identifying and considering the transportation and passengers service scenarios expected for the near, medium and long-term future, i.e. for the project baseline (2025), intermediate (2035) and final (2050) time horizons. In this paper, the main outcomes from the project activities are summarized, with particular emphasis on the studies about the definition of future scenarios and use cases for the integration of the vertical transport with the surface transport towards integrated intermodal transport system and about identification of the barriers towards this goal. In addition, an outline is provided on the specific ConOps for the integration of ATM in intermodal transport infrastructure (i.e. the part of the overall ConOps devoted to integration of different transportation means) and on the specific ConOps for the integration of ATM in intermodal service to passengers (i.e. the specific component of the ConOps devoted to design of a unique service to passengers). Finally, the main outcomes are summarized from the validation of the proposed ConOps through dedicated simulations.

1. Introduction

This paper is a further contribution in the framework already defined by previous works that accompanied the X-TEAM D2D (Extended ATM for Door-to-Door Travel) project evolution since its start in the year 2020. The project aimed to contribute addressing the challenge of performing a full door-to-door (D2D) journey, 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, in compliance with the approach of the ACARE Flightpath 2050 [1], in which the ATM and Air Transport, to which nowadays it is obviously associated the new vertical transport mode of the

Urban Air Mobility (UAM), are considered as fundamental players for the future integrated intermodal transport system expected to be able enabling 90% of travellers within Europe to complete their Door-to-Door (D2D) journey within 4 hours, experiencing a seamless journey with full connectivity. More details about the X-TEAM D2D project overall application framework have been already provided in the previous works and so are no further addressed here, in order to be able to allocate bigger room in this paper on the description of the contents indicated in the abstract. The reference papers that described the project evolution are in particular the works from [1] to [6] indicated in the references, whereas the full collection of the project reported outcomes is publicly available through the deliverables indicated in the references from [7] to [12]. It is worth noticing, finally, that the X-TEAM D2D project worked in close cooperation with siblings running projects and, in particular with reference to the UAM related aspects, cooperated and provided relevant outcomes as well as received relevant information, with efficient cross-fertilization, with the ASSURED UAM (Acceptance, Safety and Sustainability Recommendations for Efficient Deployment of UAM) project, as addressed in the reference papers from [13] to [18]. In this paper, in section 2 an outline is provided of the X-TEAM D2D project objectives and methodology and furthermore, in section 3, the scenario and use cases definition outcomes are summarized. In section 4 and 5, then, the infrastructural integration and services integration ConOps design studies outcomes are outlined, respectively. The overall designed ConOps validation activities are finally summarized in section 6 and, after that, the main relevant conclusions about the X-TEAM D2D carried out activities and outcomes are drawn.

2. X-TEAM D2D project objectives and methodology

The main objectives of the X-TEAM D2D project were the ones listed in the following:

- Definition of ConOps for ATM integration in intermodal transport network serving Urban and Extended Urban (up to Regional) mobility.
- Consideration of both currently available transportation means on the surface and water and emerging new mobility forms that are envisaged for the next decades in all dimensions (specifically UAM).
- Consideration of transportation and passengers service scenario: baseline (2025), intermediate (2035), final (2050).
- Development of a simulation-based platform for validating the proposed ConOps, considering the most relevant transport elements such as interfaces mode-mode, high-level network model, passenger-centric paradigm.
- Validation through simulation platform: qualitative/quantitative assessment against dedicated set of KPIs; diagnosis of the inefficiencies of the ConOps.

In the execution of the studies, the project implemented a methodology based on the execution of, first, the scenarios and use cases studies and, then, based on these outcomes, design of the overall X-TEAM D2D proposed ConOps. Due to the very wide scope of the target project ConOps, then, its design activities have been specialized according to two simultaneous and interacting research streams: the design of the infrastructures' integration and the design of the mobility services' integration ConOps related aspects. The overall designed ConOps has been provided as input to the dedicated validation environment that has been setup in the form of specialized simulation framework in the project. Such validation has been initially carried out in parallel and interacting with the ConOps finalization activities, leading to the final ConOps refinement, and then has been applied to the final ConOps, leading to the assessment of the related performances (quantitative, where possible, and qualitative) and possible recommendations for future improvements, beyond the project scope.

3. Scenario and Use Cases

The project first worked on critical literature analysis to define future mobility trends and to design proper scenario for integrated mobility over the future addressed time horizon. Considering the specific objective of explicitly addressing the definition of the scenario in an incremental way, the project defined not only the final target 2050 scenario but also the baseline 2025 and the intermediate 2035 ones. About baseline scenario 2025 mobility and transport related aspects, it is expected that

New Mobility Services (NMS), i.e. car-sharing, ride-hailing, bike-sharing, e-scooters, will be fully present in European cities. The CCAM (Connected, Cooperative, Automated Mobility), like automated cars and trucks, will begin to emerge. In addition, with reference to aviation related aspects, the first certified ATM Data Service Providers (ADSP) will begin advance network operations to test airspace for introduction of U-Space services. This will be enabled by airspace re-configuration, new capacity for on demand services, first harmonized standards for UAS and first certified UAS in controlled airspace accompanied by simulators and specifications for ATM Validation Platforms. There will be no dynamic interaction among transport modes, yet. Hardly any privately generated data will be available for public use and modes will continue to be optimized internally. Applications will be collecting only some information from operators. In 2035, then, it is envisaged the emerging of passenger UAM applications in experimental sites. The Core TEN-T Network will be completed enabling more intramodality among soft modes of travel, mass transit, NMS and CCAM. The transport providers will use smart pricing and, due to regulatory pressure, will shift to lower emission modes. The ATM will reach high level of automation with new ATM data service provision model, virtual centres, dynamic airspace configuration. UAS will be certifiable for all classes of airspace. The ADSP will allow for U-space testing of advance U-Space services. Transport data will be more digitalized. Transport service providers will begin implementing digitalization to shift their business models to make use of publicly available privately generated data and possibility to generate daily demand forecasts. Applications will collect more and more information from operators. Algorithmic transport governance will emerge. In the target 2050 time horizon, finally, it is expected that the EU transport will reach net-zero emissions. The Comprehensive TEN-T Network will be completed, allowing for full intramodality. A policy of walkable cities will cause domination of soft modes, mass transit, NMS and, most likely, UAM. Intercity traffic will be supplied by high-speed rail transport, CCAM and zero-emission large aircraft. By 2050, Europe’s aviation infrastructure will be completely transformed to Digital European Sky, enabling to handle the diversity of air traffic safely and efficiently, while minimising environmental impact. All operations will follow the trajectory-based paradigm. Service-oriented ATM will be scalable and highly automated. Full U-space services are expected and deployed with shorter lifecycles. Transport business digitalization will be completed allowing for system of systems level optimization and algorithmic governance. This will enable possible dynamic interaction among modes and costless reaction to disruptions thanks to excellent system flexibility. In accordance with the envisaged incremental scenario, then, the project provided the design of relevant Use Cases (UCs) to be considered for the subsequent project activities about ConOps design and validation. UCs have been detailed describing multimodal D2D travel of passengers, in the three time horizons, in urban, suburban, regional up to single small-size country part of the trips. They have been designed as ATM-centred, using air connections available in given time horizon, but, as the focus is up to regional level, in case of traditional hub or regional airports only access and regress to/from the airport has been considered. The UCs focused on irregular multimodal travels (other than i.e. daily travel to work or school): the business traveller (BT) and the visiting friends and relatives’ traveller (VFT) users. The UCs considered three variants of the course of the journey in terms of disruption: 1) no disruption; 2) disruption with info about available in advance (at least five hours before departure); 3) disruptions occurring during the journey. A total of 18 UCs has been defined, as detailed in [7], where all the outcomes of the project studies about scenario, use cases and technologies readiness are reported.

4. Mobility infrastructures integration

Based on the consideration of the future scenario, dedicated studies have been carried out to design the specialized part of the X-TEAM D2D ConOps addressing the infrastructural integration of the different mobility alternatives into a unique system allowing multimodal possibilities in terms of used transportation means for the different D2D journey legs. The main elements of the resulting intermodal system are: means, infrastructures, services, interfaces. To provide an example of the coverage implemented by the project studies, the considered transportation means are indicated in the following:

- Aeronautical/vertical transport technologies: Small Aircraft Transportation System (SATS), Short Take-Off and Landing (STOL), Vertical Take-Off and Landing (VTOL), Personal Air Transportation System (PATS).
- Road transport technologies: electric car, autonomous vehicle, autonomous (electric) bus, transit elevated bus, shared electric autonomous car, shared (electric) micro-mobility.
- Rail, water and multimodal transport technologies: autonomous rail wagon, autonomous ferry, flexible chassis systems (multifunctional vehicles).

Towards the 2025 time horizon, in order to achieve an environment that integrates UAM solutions in the intermodal transport system, it will be very important already at present to monitor and safeguard the effective use of existing urban infrastructure to better serve intermodal transportation development. In addition, it is needed to start since now, as it is indeed ongoing, the design and certification of vertipads, necessary for vehicle take-off and landing, which integrate efficiently with existing urban infrastructure. In addition, it is expected that hub airports will be connected with one or two regional airports (point-to-point connections executed by Low Cost Carrier airlines), hub airports will be connected with the city by numerous modes (trains, bus, taxi, etc.) and regional airports will provide access to one or two public transport services. To support the integration in the overall intermodal infrastructure, on the ATM side there will be work to be done especially in communications, both in terms of network and information sharing. On the Unmanned Traffic Management (UTM, i.e. the U-space ecosystem) side, then, there will be still a lot of work to be done in all aspects related to integration with ATM first and with the other parts of the integrated transport infrastructure then. About the 2035 time horizon, then, 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. It will be also fundamental 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 technology development, then, users' focus will be on personal needs as well as impact on environment. Based on that it is reasonable to envisage that relevant percentage of cars available on roads will be electric, driving performances will by highly automated and in urban areas car sharing model will be dominating. In addition, UAM for passenger transport in experimental sites will be available in Europe but without significant impact on mobility in metropolitan areas. About airports, finally, hub airports will be connected with the city by numerous modes and regional airports will provide access to more than one or two public transport services. New ATM architecture will allow the sharing of resources across the network enabling a more scalable model to all airspace users. The U-space testing phase, then, will be in progress. In 2050, finally, automation, electrification, connectivity, telematic services will simplify the relationships between 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 integrated infrastructure will take into account that all cars approved on roads will be electric, in most highly automated and autonomous, and it will be confirmed that in urban areas car sharing model will be more and more dominating. Short range airlines connections will be operated by zero emission aircraft, which will remain the air mode of transport with highest potential to impact efficiency of transport system. UAM dedicated to passenger transport will be available in Europe offering direct access to densely populated city areas. About airports, hub airports will be connected with the city by numerous collective, autonomous transport modes and regional airports will provide access to several collective autonomous transport services. ATM and UTM services will be fully operational to efficiently integrate with the overall multimodal transport infrastructure and support seamless D2D journey. Dedicated service blueprints have been finally designed, for each of the addressed UCs.

The detailed outcomes of the X-TEAM D2D studies to design the ConOps for mobility infrastructures integration are reported in [8] and [9].

5. Mobility services integration

Based on the consideration of the future scenario and in parallel to and in cooperation with the studies about infrastructures integration, then, the project addressed dedicated studies to design the specialized part of the X-TEAM D2D ConOps for mobility services integration, targeting the implementation of the Mobility as a Service (MaaS) paradigm thanks to the proposition of a Total Traffic Management (TTM) system, as outlined in the following Figure 1 [11].

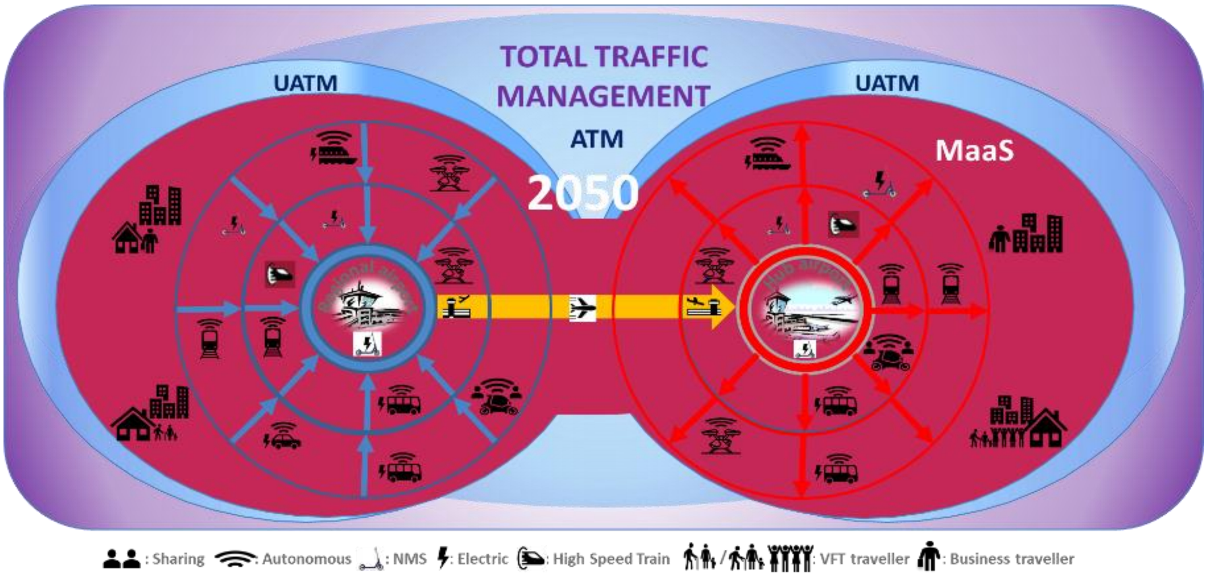

Figure 1. X-TEAM D2D proposed Total Traffic Management System for 2050 and beyond [11]

The path towards the TTM is envisaged of course as incremental. By the 2025 time horizon, ATM update will be under development and the level of automation will be increasing. Urban Air Traffic Management (UATM) will only be used for test and demonstration purposes, because UATM will be still experimental and object of research. At least first levels of U-space services will be implemented. Mobility as a Service MaaS-like elements will only be offered in some regional areas for a part of the transport modes. Traffic Information System C-ITS strategy will be intensively built up and decisively improved. By 2035, then, ATM will be upgraded to more resilient model and ATM data services providers will be fully operational. High bandwidth connection between air to ground will be available. UATM will be available in most areas, with integration of UAS into all classes of airspace accomplished and advanced U-space services in place. MaaS elements will be offered in nearly all regional areas in the origin and destination airport area and Traffic Information System will be very effecting in disseminating the related data. In 2050, finally, ATM will be highly automated and will implement a passenger-centric and services-oriented approach. UATM will available and functional in all areas. High level of connectivity and digitalisation will be available, supporting all automated functions with U-space full services available. MaaS will be possible for complete D2D travel, including the flight segment. C-ITS will be fully effective and collected data will bring the system to an excellent level.

The detailed outcomes of the X-TEAM D2D studies to design the ConOps for mobility services integration are reported in [10] and [11].

6. ConOps validation

The project designed ConOps has been finally validated by the construction of a simulation model of a high-level D2D case study, with the aim of assessing the performances, feasibility and limitations of the ConOps and identifying the areas of improvement between ATM and the different modes of transport. The simulation model included two parts: the regional airport and related addressed surrounding area (namely Brunswick, served by Hannover airport) and the hub airport and related addressed surrounding area (namely Haarlem, served by Schiphol airport). The simulation model maintained the same structure but included different transport options in 2025, 2035 and 2050. The model implemented both the different existing transport options and perspective transfer possibilities compliant with the X-TEAM D2D designed ConOps, using real-life distances (GIS-Based) and real-life travel times (GIS-based) for the existing possibilities. It included moving objects (carrying info), such as passenger groups and transport entities, and static elements (Capacitated nodes), such as transport network and transfer stations. The schematic representation of the simulation model is reported in the following Figure 2 [12].

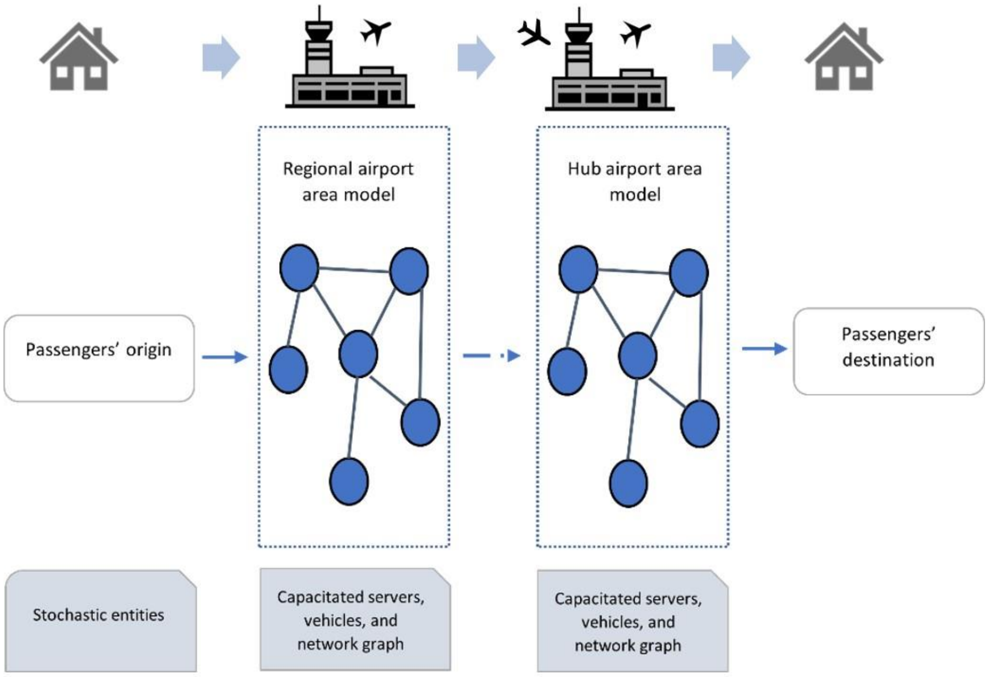

Figure 2. Schematic representation of the X-TEAM D2D proposed ConOps simulation model [12]

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 3. X-TEAM D2D considered set of KPAs and KPIs in the proposed ConOps validation [12]

The ConOps assessment has been also supported by the project appointed Passengers Advisory Group (PAG) and finally included both quantitative (simulation-based) and qualitative (experts' assessment-based) evaluation of the performances against dedicated set of Key Performance Areas (KPAs) and Key Performance Indicators (KPIs), as summarized in the previous Figure 3 [12]. The ConOps demonstrated its effectiveness in enabling seamless integration of the different transportation alternatives, by 2050 time horizon, into unique D2D passengers' journey supported by integrated mobility infrastructures and service including as mayor player aviation and UAM, efficiently supported by fully integrated ATM and UAM systems.
The detailed outcomes of the X-TEAM D2D ConOps validation activities are reported in [12].

7. Conclusions

The X-TEAM D2D project activities have been successfully concluded in 2022 and delivered several relevant results. First, the project provided the definition of future scenarios and use cases for the integration of the vertical transport with the surface transport towards integrated intermodal transport system and the identification of the resulting barriers. Based on that, the project carried out the design of the ConOps for integration of ATM and aviation, as well as UTM and UAM, in intermodal transport infrastructure and the parallel and cooperative design of the ConOps for the integration of ATM and UTM into overall intermodal service to passengers. The resulting overall ConOps for the seamless integration of ATM and air transport into an overall intermodal network, including other available transportation means (surface, water), to support the door-to-door connectivity has been finally successfully validated by means of dedicated simulation environment setup by the project as well as external experts assessment. The validation results indicated the feasibility and effectiveness of the proposed ConOps in achieving its target as well as allowed providing suggestions for its future development and improvement, beyond the project scope.

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