An Outline of A Concept of Operations For Integration of ATM and Air Transport into Multimodal Transport System For Door-To-Door Travel

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AN OUTLINE OF A CONCEPT OF OPERATIONS FOR INTEGRATION OF ATM AND AIR TRANSPORT INTO MULTIMODAL TRANSPORT SYSTEM FOR DOOR-TO-DOOR TRAVEL

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Abstract

In the framework of the research activities supported by SESAR JU, dedicated research stream is devoted to investigation of integration of Air Traffic Management (ATM) and aviation into a wider transport system able to support the implementation of Door-to-Door (D2D) travel concept. In this framework, the project X-TEAM D2D (Extended ATM for Door-to-Door Travel) has been funded by SESAR JU under the call SESAR-ER4-10-2019: ATM Role in Intermodal Transport, with Grant Agreement n. 891061. The project aims defining, developing and initially validating a Concept of Operations (ConOps) for the seamless integration of ATM and air transport into an overall intermodal network, including other available transportation means (surface, water), to support the door-to-door connectivity, in up to 4 hours, between any location in Europe, in compliance with the target assigned by the ACARE SRIA FlightPath 2050 goals. The project is focused on the consideration of ConOps for ATM and air transport integration in intermodal transport network serving urban and extended urban (up to regional level) mobility, taking into account the transportation and passengers service scenarios envisaged for the next decades, according to baseline (2025), intermediate (2035) and final (2050) time horizons. In this paper, the outcomes of the first phase of the project activities, aimed to provide the initial definition (concept outline) of the proposed overall ConOps are illustrated, emphasizing the specific activities that have been carried out up to date and the related achievements. In addition, an outlook is provided in the paper on the next project activities, expected to be carried out towards the conclusion of the studies and the validation, by means of dedicated numerical simulation campaigns, of the proposed ConOps.

Introduction

In recent years, the Air Traffic Management (ATM) and Air Transport are being increasingly considered as part of an intermodal transportation system, rather than standalone transportation means. Such perspective puts the passenger as the center of the overall integrated transportation system so that the passenger's journeys consists of a succession of different transport modes that have to be facilitated as seamless as possible, depending on individual transport modes availability, on passenger's individual preferences regarding travel time, comfort, environmental impact and other criteria. Based on this driver, 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 has been considered in the ACARE Flightpath 2050 [1], in which the ATM and Air Transport are considered as a component of primary relevance of an integrated intermodal transport system that will be able to allow 90% of travelers within Europe to complete their door-to-door journey within 4 hours, experiencing a seamless journey with full connectivity.

In this framework, SESAR JU launched in 2019 a Call for Proposal addressing Exploratory Research activities including as specific topic the study of the ATM Role in Intermodal Transport, aimed to allow more detailed understanding on how ATM can better contribute to improve passenger's intermodal journeys and how to increase the performance of the overall transportation system [2]. The X-TEAM D2D (eXTEnded AtM for Door2Door travel) project has been funded based on the positive evaluation of the related proposal and the project started its activities in June 2020, with target date for completion of the studies set to September 2022. The project consortium includes CIRA as leader, ISSNOVA (with linked third party ISINNOVA), DLR, ILOT, D-Flight, and HVA (Amsterdam University of Applied Sciences) [3].

X-TEAM D2D project aims to define, develop and initially validate a Concept of Operations (ConOps) supporting the seamless integration of ATM and Air Transport into an overall intermodal network, including other available transportation means (surface, water), to contribute enabling the door-to-door connectivity, in up to 4 hours, between any location in Europe, in compliance with the target assigned by the ACARE SRIA FlightPath 2050 goals [1].

More in particular, the X-TEAM D2D project is focused on the detailed consideration of ConOps for ATM integration in intermodal transport network serving Urban (i.e. considering the relevant role that Urban Air Mobility (UAM) will play) and Extended Urban (up to Regional) mobility, taking into account the transportation and passengers service scenarios envisaged for the next decades, according to baseline (2025), intermediate (2035) and final (2050) time horizons. From the practical point of view, the project addresses the specific multimodal transport scenario addressing the passenger's D2D journey between a big metropolis, where big hub airport is available, and a smaller city, served by regional airport.

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

In the project activities, the integration of ATM and air transport into overall intermodal transport system is considered not only with respect to currently available transportation alternatives on the surface and water but also with respect to emerging new mobility forms that are envisaged for the next decades.

Up to date, the project performed relevant activities and achieved some important results. In particular, the project team completed 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. The activities carried out in this framework and the related achievements are outlined in the dedicated section of this paper.

In addition, the project carried out the first phase of the activities devoted to the design of an overall ConOps that is divided into two main components: a 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 a 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). The two ConOps components have been defined up to date in their initial version (Concept Outline) and their refinement towards the final version (Concept Description) will be carried out in the prosecution of the project activities. The activities carried out in this framework and the related achievements are outlined in the dedicated sections of this paper, with specific reference first to the integration of ATM in intermodal transport infrastructure, and then to the integration of ATM in intermodal service to passengers.

The project, then, carried out also the initial phase of the validation activities, by setting up the simulation framework and performing initial study of business passengers' journey in 2025 and 2035, based on the available initial version of the project proposed ConOps, as constituted by its two initial components above-indicated, and providing first feedbacks. The activities carried out in this framework and the related achievements are outlined in the dedicated section of this paper.

Finally, in the paper some conclusions are summarized and the future work foreseen in the X-TEAM D2D project is outlined.

Scenarios and Barriers

The project activities have been devoted to definition and description of crucial specifications of systemic environment in which future integrated metropolitan and regional transport would operate [4]. Such activities constituted a foundation for definition of the Concept of Operations defining the role of ATM and air transport in the three considered time perspectives (2025, 2035 and 2050), in terms of both physical and informational dimension. Four main aspects have been addressed, as summarized in the following.

Urban and suburban mobility reference scenario - Reference scenario has been defined with particular reference to urban and suburban mobility, reflecting the dominating trends in this framework. The results of the work indicated the world will change much after COVID-19, giving the way to a new system, less individualistic, preserving public goods, economic security, and inclusion, like in the EU, where climate action and reconstruction to more efficient industrial systems, buildings, and vehicles to reach net-zero emissions became a leading priority. To reach this goal it will be considered also the opportunity to make use of next generation nuclear power plants as a low-carbon energy source alternative to fossil fuels. In the transport sector, the EC policy follows its circular economy paradigm aiming to complete the networks, further the sustainability, redefine airspace management, and make use of the emerging technologies (Internet of Things, smart cities) while protecting freedoms and leaving no one behind. For passengers, it means protection of their needs: convenience, easiness, frequency & speed of service, exhaustiveness and reliability. Moreover, for the active elderly, an expected large share of future passengers, some extra features will have to be added to the system: affordable, barrier free, comprehensible, friendly, safe, secure, transparent and complementary.

Technologies for urban/suburban mobility - Detailed analysis has been carried out aiming at identification and evaluation of new technologies related to transport modes that represent potential to significantly impact the intermodal mobility of people in the three considered time horizons.

In air transport, two main domains can be identified as dominating:

1) Classic aircraft configurations, such as Small Air Transport System (SATS) and Short Take-Off and Landing (STOL) vehicles: for both of them, the technology is almost already available but other advances will still have to be achieved especially in safety assurance and affordability.

2) New configurations, which will take advantage from technology progress in the area of drones, electric propulsion, but also miniaturization of jet engines (Jetpack), represented by VTOL and PATS categories [5]. The technology is seen as, perhaps, the most important element for Urban Air Mobility (UAM).

When surface transport is considered, rather no new vehicles types is predicted to appear in given time horizons: road, rail, and water modes will be a subject of evolutionary change rather that disruptive. For all means of transport two main trends can be identified:

1) Electrification: zero emission goal for 2050 requiring elimination of fossil fuels. Electric propulsions are seen as solution for urban mobility of future.

2) Automation and autonomation of transport: especially important for public, mass means of transport as enabler for increase of efficiency and flexibility. This trend is also present in rail as well as water transport (and air modes as well).

Shifting on the multimodal level of transport, the consideration turns the focus on communication, which is an important enabler for integration and coordination. Exchange of data between modes is the main driver for achieving relevant needed progress in the field of transport efficiency and sustainability, allowing for optimization on the level of entire transport ecosystem and opening the door for future integrated, inter-domain, metropolitan transport system.

Use Cases - Identification and specification of use cases for the intermodal transport system including ATM and air transport with reference to the three considered timelines (2025, 2035, 2050) has been performed. Scenarios have been defined, by providing the examples of travels with all the steps required in the given time horizons. These use cases have been designed as a form of validation and verification of scenarios consistency in numerous dimensions.

Barriers against 2D and air transport integration - Identification and description of barriers disabling efficient integration of vertical and surface modes of transport has been carried out. Implementation of all assumptions and turning defined use cases into real cases require overcoming of numerous barriers of various nature. Four groups of barriers have been identified:

1) 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.

2) Digitalization, as one of enablers for exchange of information: it corresponds to cost of investment and upgrading of current management systems, as well as or mainly need for standards, recommendations and regulation covering future data collecting, processing and sharing to be defined. The digitalization should also cover high level management of complex transport ecosystems (algorithmic governance).

3) Hardware technology availability: development of solutions enabling safe, reliable and efficient operation of autonomous vehicles for passengers' transport (full electric VTOLs) and necessary ground infrastructure.

4) Development of dedicated, adequate standards for new mobilities and unconstrained data collecting, processing and sharing: the data are seen as main determinant of future transport integration process. Addressing the standards and recommendations for real-time exchange of all types of data (including privately generated) between operators and all interested parties is crucial.

Integration of ATM in intermodal transport infrastructure

Dedicated activities are devoted in the X-TEAM D2D project to the definition of a ConOps supporting the seamless integration of ATM into an overall intermodal network from the perspective of the transport systems and infrastructures [6]. At the current stage, the activities led to the provision of the initial definition (i.e. the Concept Outline) of such ConOps for ATM integration in intermodal transport system, with the conclusion of many supporting and needed studies addressing:

- the identification of potential technological solutions over the three time horizons (baseline 2025, intermediate 2035, and final 2050) considered in the project;
- the identification of the barriers, in terms of regulations and operational standards for aircraft intended to operate in Unmanned Traffic Management (UTM/U-Space) system (with regard to performance and equipment, both for manned and UAM);
- the identification of enabling and most relevant projects or activities addressing the barriers.

Based on that, fulfilment of barriers has been addressed and assessed, with the description of degree the projects or activities address the barriers. In addition, the activities allowed to achieve the very important results indicated in the following:

- definition of the objectives of the intermodal system;
- setting of the service blueprinting methodology for the intermodal air travel, which will lead to service blueprint definition in the future dedicated project activities;
- definition of the Canva/template of the X-TEAM D2D Service Blue Print supporting the definition of the ConOps;
- definition of a high-level intermodal system architecture, including: associated structure (architecture outline), main elements identification with respect to each of the three time horizons (preliminary architecture components description);
- identification of the role that ATM and UTM play in the intermodal system over the three considered time horizons;
- provision of some considerations related to disruptions management.

The approach implemented in the X-TEAM D2D project activities is based on the consideration that ConOps will have to respond to user needs and be consistent with the evolution of the global economy. Mobility is at the heart of the project and the concepts proposed must be attractive in terms of sustainability and advantages offered. The main advantage offered by the X-TEAM D2D proposed ConOps is the passenger-centric approach that puts passenger needs and desires at the center of future solutions, introducing the fundamental concept of passenger trajectory while taking into account and contributing enabling the door-to-door connectivity.

The integration of ATM and air transport into overall intermodal transport system has been considered not only with respect to currently available transportation alternatives on the surface and water but also with respect to emerging new mobility forms that are envisaged for the next decades.

Moreover, the project analysed both the *status quo* of different transport modes in Europe and the emerging ones that new technology is developing, all of them immersed in the on-demand and shared economy, which will revolutionize future transport modes in combination with the passenger-centric view. At a high level, the elements of multimodal mobility system and their relationships according to envisaged intermodal transport system architecture have been outlined in the ConOps, distinguishing the three time horizons considered in the project, namely 2025, 2035, 2050, by using as a starting point the use cases defined in the project.

In this study, dedicated focus has been placed on the consideration that, 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, institutions.

The aspects related to infrastructures integration (physical integration, network integration, vertical vehicles integration with surface ones) have been considered and relevant emerged considerations are summarized in the following.

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, the following airport considerations apply: connecting hub airports with one or two regional airports (point-to-point connections executed by LCC airlines); hub airport is connected with the city by numerous modes (trains, bus, taxi, etc.); regional airports provide access to one or maximum two public transport services.

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 airport will be connected with the city by numerous modes and regional airports and will provide access to more than one public transport services.

2050 time horizon - Automation, electrification, connectivity, 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, 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 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 services.

Future work will address the final service blueprint definition, the final integrated transport system high-level architecture and components definition, the refinement of ConOps about role of ATM and UTM in the intermodal transport system, the extension of disruptions considerations, the possible definition of high-level system requirements of the intermodal transport system.

Integration of ATM in intermodal service to passengers

The research methodology in this framework is focused on a ConOps for a regional D2D trip with a flight segment for passengers, the core of which is a conventional ATM, which is to be enhanced by a variety of management systems and applications [7]. The proposed ConOps tries to find solutions for the future to lead in a total traffic management [1][8][9][10][11].

The ConOps for ATM integration into multimodal transport will describe the characteristics of the proposed system from the perspective of passengers and transport modes through several use cases in 2025, 2035 and 2050.

In addition, current extension approaches - such as Airport Collaborative Decision Making (A-CDM) [12][13][14], Total Airport Management (TAM) [15] and European ATM Master Plan [16] gain further aspects for a comprehensive Total Traffic Management, in which the passengers, but also the other stakeholders, are the focus to generate a benefit for the overall system [17].

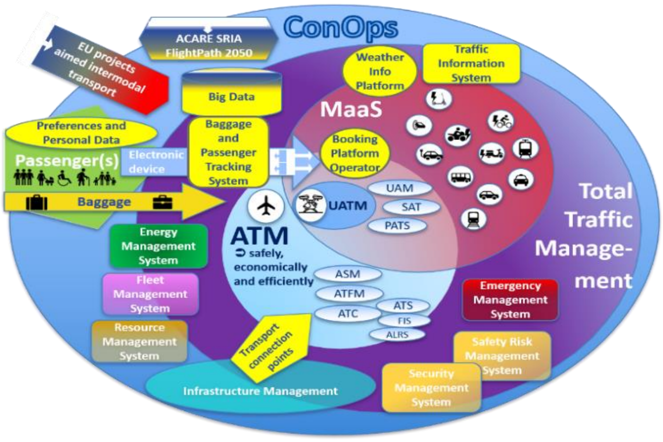
Components for a Concept of Operations for ATM service to passengers in intermodal transport

In this ConOps, the focus is on the passengers, so that sustainable success is achieved if this system attracts and retains the confidence of customers/passengers and other relevant interested parties. An increase in satisfied and loyal customers means a flourishing overall system and thus added value for the other stakeholders in the system [17][18]. Every aspect of passenger interaction offers an opportunity to create more value for the customer. Efficient management and cooperation in the different areas enable optimisation and harmonisation of the overall system [19][20].

Therefore, the ISO basic concepts and principles for Quality Management Systems (QMS) flow into these ConOps. They represent a modern form of work organization and corporate governance with which the management of any organization, including the transport sector, can achieve its goals [19][21]. The management and service components of the ConOps are shown in Figure 1.

This system aims to ensure that, by taking greater account of passengers' preferences, safety is improved, and capacity and operational efficiency are increased. This is achieved by building processes and systems to help passengers to realize their preferences.

In addition, information is collected, collated, monitored, evaluated and shared through the management systems. Research and analysis will determine the appropriate division of tasks between systems. This will include determining when decision support is needed to assist humans and when functions must be fully automated.



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

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

Extended ATM Concept of Operations for passenger service

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

The management systems, the tools and the "intelligence" of the algorithms, which will become the intermodal system, play a decisive role in achieving the ambitious goal of providing complete traffic management for a door-to-door connection in up to four hours. The elements are to be viewed broadly, as service tools are also included, for instance. While new technologies will improve the means and infrastructures, it is also evident that the system's functioning depends heavily on service quality [8][10][11].

Architecture outline in the 2025 timeframe

In 2025, the implementation of electric vertical take-off and landing aircrafts (eVTOL) for UAM operation will take place as 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, escooters, 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 optimising travel costs of different modes, ticketing interoperability (flexible in case of disruptions) and integrated tickets will be available in some areas. There is still a high level of difficulty to integrate the ATM and U-Space system [22]. Envisaged architecture for 2025 time horizon is described in Figure 2.

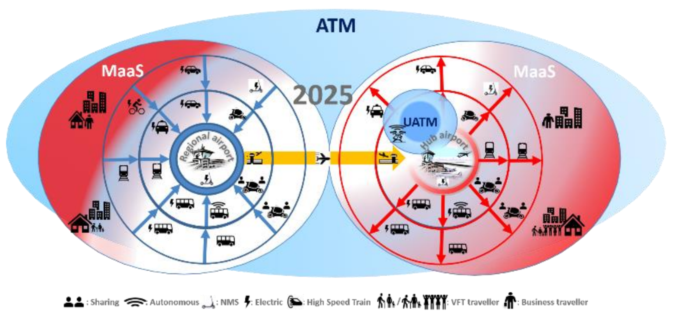


Figure 2. Time horizon 2025 on the way to total traffic management.

There is still a lack of tools for the exchange and use of data between the different transport modes in the immediate future. In addition to the passengers, the whole system would benefit considerably from an improvement in this condition. The efficiency of the transport process still depends on the passenger's ability to manage their journey. Unfortunately, ATM operations have not yet become passenger-centric, partly because performance targets did not consider the impact on passengers. In addition, the complexity of the ATM network does not allow for the desired response in the event of a disruption. The existing ATM works with a well-established and proven safety management system, but it does not allow for rapid developments and implementations. In contrast, U-Space is innovative and fast, but its level of security and robustness is not defined nor 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. During 2025, conformance monitoring will rely on currently available Air Traffic Management - Communication, Navigation and Surveillance (ATM CNS) capability and ATM and regulatory reporting mechanisms. In 2025, there will be an opportunity to increase surveillance and communications coverage by implementing systems such as Automatic Dependent Surveillance-Broadcast (ADS–B) and other communications 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. However, a data collection system will need to be implemented. It will be necessary to define where and/or under what scenarios Conformance Monitoring will be necessary.

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

Architecture outline in the 2035 timeframe

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

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

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

Envisaged architecture for 2035 time horizon is described in Figure 3.

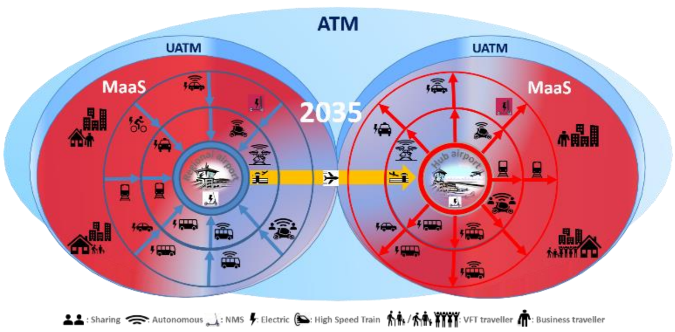


Figure 3. Time horizon 2035 on the way to total traffic management.

Architecture outline in the 2050 timeframe

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

By the 2050-time horizon, a highly automated ATM system with 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. C-ITS traffic systems will use all aspects of cooperative, connected and automated vehicles. The collected data will bring the traffic information system to an excellent level. In addition, strategic planning of traffic flows will be improved, reducing the imbalance between capacity and demand. Based on accurate and complete data, changes and disruptions can be resolved without loss of travel time.

Mobility-as-a-Service will be possible for every traveller for door-to-door travel, including flight segment (Figure 4).

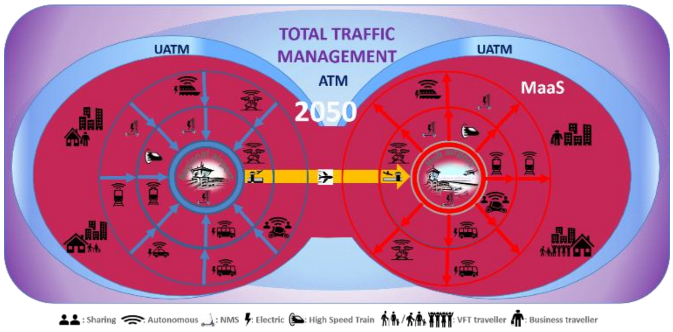


Figure 4. Time horizon 2050 on the way to total traffic management.

This section presented the management and service applications of a ConOps, which should lead to Total Traffic Management until 2050. The ConOps got a core of the conventional ATM covered by operational steps defining a D2D journey with a flight segment for a passenger, which shall be improved by the multiple management systems and applications components. The development of a selection of possible management systems was shown in the different time horizons: 2025, 2035, to 2050.

In addition, Figure 5 shows the optimal configuration of the ConOps with all their management systems, instruments and applications as an extended ATM operating concept for passenger services, as here described.

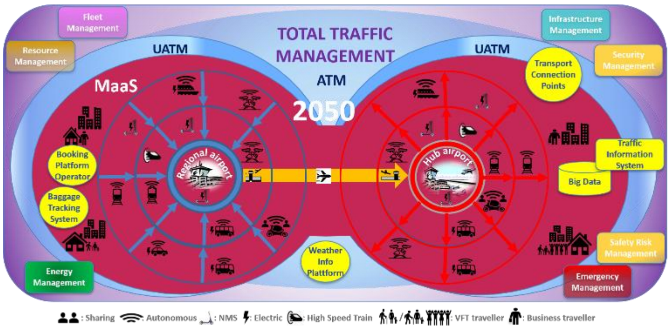


Figure 5. Total traffic management in 2050.

Validation of the ConOps

For validation of formulated ConOps, the X-TEAM D2D project has developed a simulation framework. The framework consists of two parts, which represent door-to-airport and airport-to-door phases of the passenger journey, and it is implemented in a general-purpose discrete event simulation software [23].

Simulation model description

The goal of the developed simulation framework is to evaluate the impact of future concepts of operations on the passenger journey in 2025, 2035 and 2050. The simulation framework is based on a multiple-layer approach, which means that, first, the existing transportation network is created and verified. Current public transport information and statistics is used for verification of travel times, distances, and operational rules of transport modes existing in 2020. Then, future transport technologies are added to the model considering corresponding time horizon assumptions and ConOps.

The framework consists of three groups of elements:

- The first group, *dynamic entities*, represents passengers and vehicles transporting passengers from their origin to the airport.
- The second group, *static elements*, represent transport stations that the passengers can use to embark/disembark on and off transport vehicles. These stations serve as the entry, transfer, and exit points with a fixed position 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.

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

In the model, the arrival of passengers and most of transportation means is 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.

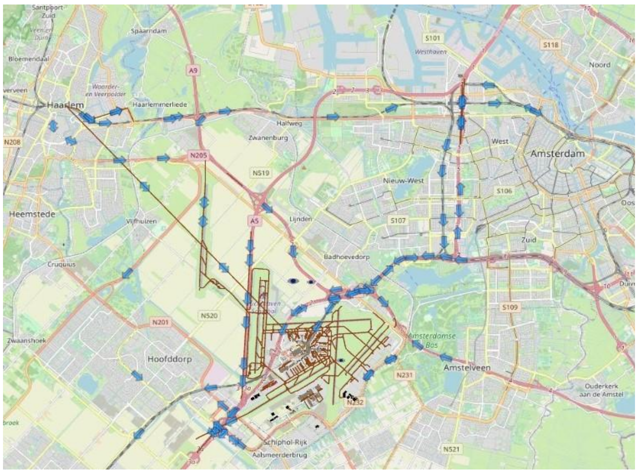


Figure 6. Door-to-airport part of the X-TEAM D2D simulation model

Set up of simulation experiments

A series of simulation experiments will be run using the developed framework to validate the defined ConOps. These experiments consist of multiple runs according to nine scenarios characterizing 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, series of indicators will be tracked to evaluate the performance of ConOps in each scenario. These indicators will include total travel time, total travel distance and other indicators that will be developed during the next phases of X-TEAM D2D project.

After performing the experiments, the results will be analyzed and the conclusions about the functionality of the developed ConOps will be made. An example of such results and analysis can be found at first X-TEAM D2D study of business passengers' journey in 2025 and 2035 [24].

Conclusions

This paper outlined the motivations and objectives of the X-TEAM D2D project and summarized the activities carried out up to date and results achieved so far. In particular, the paper outlined the considerations emerged from the work carried out in the project about: 1) 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; 2) the integration of ATM in intermodal transport infrastructure; 3) the integration of ATM in intermodal service to passengers; 4) the initial phase of the validation activities.

Future work will be devoted in the project to the refinement of the overall ConOps for ATM integration in intermodal transport infrastructure and for the associated unique intermodal service to passengers and to the validation of this proposed ConOps.

Finally, recommendations emerging from the project studies will be provided.

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