Extended ATM for Seamless Travel (X-TEAM D2D)

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Abstract

X-TEAM D2D project is focused on integrating Air Traffic Management and Urban Air Mobility into an overall multimodal transport network to address the potential increase in efficiency of the overall transportation system in the future, considering the operational domain of the urban and extended urban environment up to a regional extent and passenger-centric perspective. This paper presents the analysis of the Door to Airport trajectory of business passengers until 2035. The results indicate the system's expected performance in 2035 under normal and disrupted scenarios providing insight on the expected impact of future technologies.

Keywords: *airport, multimodal transport, passenger service, door-to-door*

1 Introduction

The world population will increase to approximately 10 billion people in 2050 and approximately 11 billion around 2100. By 2050, about 68% of the worldwide population will live in urban areas (United Nations, 2019). This growth will dramatically increase mobility and demand for transport, especially air travel demand.

In future (up to 2050), physical infrastructure, transport systems, traffic management, operational processes and information systems will be seamlessly integrated. Combining emerging information technologies and transport modes with a passenger-centric view will revolutionise future mobility (Organisation for Economic Co-operation and Development and International Transport Forum, 2020). From the aviation perspective, a key enabler for this is integrating Air Traffic Management (ATM) and Urban Air Mobility (UAM) and related U-Space services into overall multimodal transport systems that will provide its stakeholders with standard and comprehensive information of the door-to-door (D2D) travel flows and improve accessibility and passenger service level (Bao et al., 2016). To achieve such integration and facilitate reaching the goals of Flightpath 2050 (European Commission, 2011), it is necessary to explore how different existing, emerging, and new transport technologies can be integrated and define the related integrated service concept as well as the policies that could help such systems function most efficiently. These tasks comprise the scope of the X-TEAM D2D project.

This paper presents preliminary results of simulation experiments for the business traveller's use case considering technological changes in the passenger journey in 2025 and 2035 and is organised as follows. Section 2 introduces project goals. The project methodology and the relevant elements are described in Section 3. Modelling and simulation approach for validation of Concept of Operations (ConOps) is presented in Section 4. First simulation experiments with the ConOps validation tool are described in Section 5, and their preliminary results are discussed in Section 6. Section 7 concludes the paper and discusses future work direction.

2 Project Goals

The X-TEAM D2D project aims to explore and analyse the integration of ATM (and UAM with related U-Space services into the overall multimodal transport system, considering currently available transportation modalities and the emerging mobility forms envisaged for the next decades. Moreover, the X-TEAM D2D focuses on developing the ConOps for seamless D2D mobility in urban and extended urban areas (up to

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regional). The developed ConOps will be validated and evaluated against relevant key performance areas and performance indicators, using a simulation-based platform that considers the most relevant future transport elements. Furthermore, specific use cases of the D2D journey under different scenarios will be analysed to validate the ConOps and enable decision support tools.

The X-TEAM D2D will bring the following improvements in the state-of-the-art research:

- Enhancing understanding of seamless D2D travel in integrated ATM and multimodal transport modes.
- Integrating modelling D2D travel into ATM and multimodal transport.

3 Methodology

The X-TEAM D2D research methodology comprises the definition and validation of the ConOps, based on reference scenarios and application in use cases. 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. Figure 1 shows the project methodology, which includes extensive literature research as well as use of public transport data from different existing mobility service providers. In cases, where are no data available, e.g., for future mobility technologies, the project members agree on assumption regarding the required operational parameters.

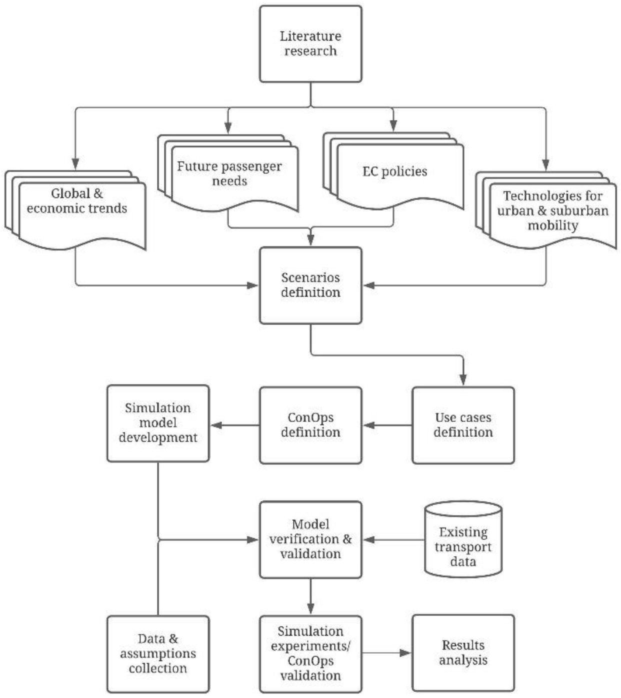


Figure 1. X-TEAM D2D methodology flowchart.

3.1 Reference Scenarios Definition

To formulate ConOps applicable to three considered time horizons, three reference scenarios describing the state of the transportation system in these years were defined. They assume that energy transition, green mobility and transport, and circular economy will occur in 2025 and 2035, supported by a significant increase in digitalisation and automation in 2050 (Eurocities, 2021). The defined scenarios are not alternatives but subsequent possible future states. The analysis of the potential integration of ATM and other modes shows that most technologies will be partly achieved by 2035 (electric vehicles, autonomous/electric bus in connection with the airport, transit elevated bus, autonomous cars, shared electric micro-mobility) and fully deployed by 2050. The defined reference scenarios characteristics are as follows:

In 2025:

- Intensifying use of New Mobility Services (NMS) (Kamargianni et al., 2016), emerging of connected, cooperative, automated mobility (CCAM) (European Comission, 2018).
- Further development of Trans-European Transport Network (TEN-T) (mainly rail and maritime) (European Comission, 2021), shift to rail and maritime logistics.
- Million public recharging stations and 500 hydrogen refuelling stations (European Commission, 2020).
- Eurovignette (AGES, 2021).

In 2035:

- Emerging of UAM, intensifying use of CCAM.
- The Core TEN-T Network completed, smart pricing, shift to lower emission modes.
- Three million public recharging stations and 1000 hydrogen refuelling stations.
- Intensifying multimodality among the soft modes of travel, mass transit, NMS, CCAM.

In 2050:

- Net-zero emissions in transport.
- The Comprehensive TEN-T Network completed.
- Walkable cities, domination of soft modes, mass transit, NMS, CCAM, UAM.

The scenario development adopted and implemented a passenger-centred approach, which incorporates concepts of inclusive design, transgenerational design, and context of use. Inclusive design aims to optimise the use of a system or a service for a specific user with specific needs. Eventually, inclusive design results in a system and/or service accessible to and usable by as many people as reasonably possible without the need for adaptation or specialised design for specific user categories. The inclusive design embeds the concept of transgenerational design, aiming to make systems and services compatible with physical and sensory impairments associated with human ageing (Pirkl, 1994). Thus, the inclusive design considers the full range of human diversity to cover individual passengers' permanent or temporary needs (Inclusive Design Research Centre, 2021). The concept of context of use represents the combination of goals, characteristics, tasks, objects and environment describing the situation in which the users operate a system or service. The context of use considers the variety of real-world contexts under different time horizons, concerning which transport mode is more efficient and responds better to the needs of travellers.

The passenger-centred approach allows the identification of the main actions of passengers and their characteristics during the multimodal D2D journey. Based on the three scenarios mentioned in Section 3.1, a set of most representative use cases was defined. These use cases are "ATM-centred", meaning that they include the central role of ATM in multimodal transport.

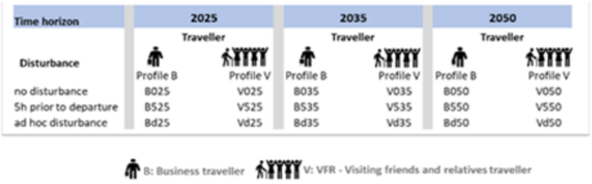
3.2 Definition of Use Cases

Definition of the use cases for a given time scenario consists of the identification of the most representative passenger profiles, the expected mobility patterns, the identification of new modes of transport, and the integration of ATM with multimodal transport modes through data exchange, with special focus on tools and solutions that enable efficient travel planning, management and resilience to various disruptions.

To determine the relevant passengers' needs, the following key aspects were considered:

- Services and facilities should have affordable prices, considering the demand market segmentation.
- The options and solutions provided should be easy to use and easy to understand.
- Frequent railroad connections to the city centre should be an asset if an attractive alternative to road-based transport to/from airports exists.
- Information provided should be exhaustive and of high quality, particularly in case of disruptions.
- Reliability of services should be guaranteed by providing alternative solutions, e.g., in case of unexpected disruptions.

The specifications of the use cases include type, characteristics, profile and expected behaviour of different passengers, new modes of transport, the transport integration and data exchange that cover planning, management, and resilience to disruptions during multimodal D2D journey. In total, 18 use cases were identified. Figure 2 gives an overview of the defined use cases and the corresponding scenarios.



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

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

Figure 2. Overview of use cases within the time horizons.

The key characteristics of passengers' profiles and their expected behaviour are based on the distinction between two types: the business traveller (BT) and visiting friends and relatives (VFT). These characteristics and corresponding expected behaviour are then projected in the future according to three time horizons: 2025, 2035 and 2050. Table 1 gives an example of the BT key characteristics and corresponding behaviour in 2035.

Table 1. Business traveller profile key points for 2035.

Characteristics	*Expected behaviour*
• Travels alone (mainly). • Very high comfort standard. • Expect a very short travel time. • Few budget limits. • Travels for a short stay, small luggage. • Frequent traveller. • Adult (18-70 years), generally in normal health condition (minor physical or sensorial impairments). • Relies on dedicated business services for travel arrangements (no reservation or payment methods constraints). • Complete flexibility for a travel plan change.	• Spends little time in planning the trip; the trip is not arranged a long time in advance. • Personalised/on-demand travel services, even at higher costs. • Chooses the fastest multimodal journey combination. • Chooses the most comfortable, effortless travel means. • Might choose travel means to show status, according to the position in the organisation. • Might choose travel means to reinforce sustainability policies of his/her company.

Various assumptions have been made for specifying current and future transport modes in determining the use cases according to the defined scenarios. For example, in scenario 2025, it is assumed that data sharing will impact the efficiency of the transport system, especially short-range airlines connections. There is a good connection between the hub and regional airports, and there is a good connection between the hub airport and the city by numerous transport modes (trains, bus connections, taxis).

4 Modelling and Validating ConOps

An essential part of the X-TEAM D2D project is developing a simulation framework for evaluating and validating the created ConOps. This framework represents high-level door-to-door travel where target passenger groups use different transport means to reach their destination. As X-TEAM D2D is focused on the role of ATM and airports in future multimodality, the simulation framework is built around two types of airports: regional airport and hub airport.

The framework consists of two parts which represent door-to-airport and airport-to-door phases of the passenger journey. The schematic representation of typical passenger journeys simulated in the framework is shown in Figure 3. This paper presents only the first half of the door-to-door trip of the simulation framework, reflecting the business traveller's door-to-airport journey in 2025 and 2035. The characteristics of the model and simulation experiments set up are described in the following sections.

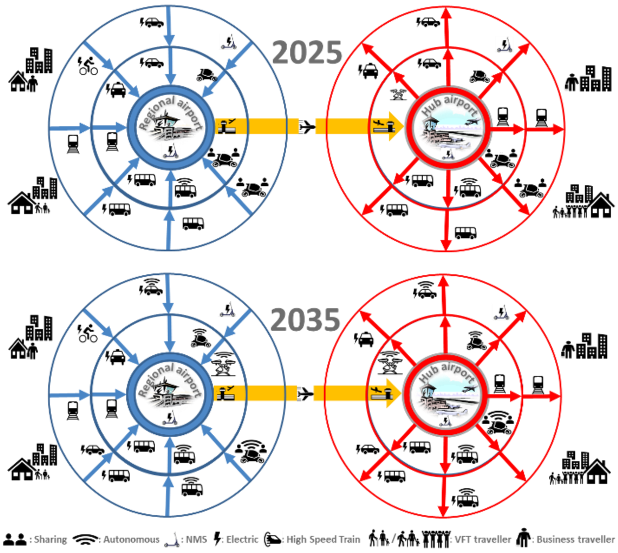


Figure 3. Multimodal passenger trips in 2025 and 2035.

4.1 Simulation Model Architecture

The developed simulation framework aims at evaluating the impact of future concepts of operations on the passenger journey. The simulation framework is based on a multiple-layer approach, where first, the existing transportation network is created. Then, future transport technologies are added on top of that as an additional layer considering relevant time horizon assumptions and ConOps. Such an approach allows simulating different time horizons using the same simulation model, which reduces required model building time and allows flexible integration of different transport means into an overall multimodal network.

There are three groups of elements implemented in the model. The first group, dynamic entities, represents passengers and vehicles transporting passengers from their origin to the airport. The second group, static elements, represent transport stations 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 4 shows a part of the simulation model representing door-to-airport journey.

Figure 4. X-TEAM D2D simulation model view.

In the model, the arrival of passengers and most transportation means is generated stochastically based on the initial assumptions. Some transport means (such as buses and trains) are generated on a schedule, as observed in real-life operations. An overview of modelling assumptions is given in Section 4.2.

The model is implemented in a general-purpose discrete event simulation software, using the concepts described above.

4.2 Modelling Assumptions

In the simulation model, the following transport technologies have been considered:

- Public buses
- Railroad transport (trains)
- Taxi vehicles, running on fossil-based fuel
- Electric scooter or similar form of individual transport (eScooter)
- Electric taxi vehicles (eTaxi)
- Electric vertical take-off and landing aircraft (eVTOL)

The following assumptions have been considered in the model:

- The road infrastructure and its operational conditions remain unchanged through all time horizons and correspond to the existing infrastructure state in 2020.
- Only individual business passengers travelling to the airport are simulated.

- Passenger arrival remains stochastic across scenarios and follows the same distribution as shown in Figure 5. The arrival rate pattern was adapted from NV Nederlandse Spoorwegen (2020).
- All passengers have pre-purchased travel tickets; therefore, no purchasing time is 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 are carbon-neutral (electric transport).
- eVTOL operation does not consider possible airspace limitations and regulations.

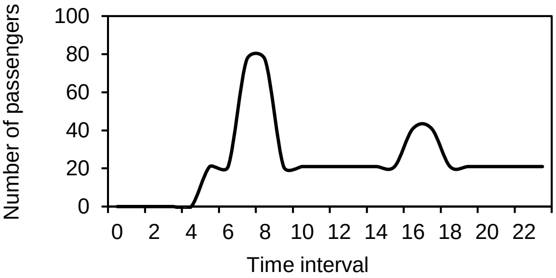


Figure 5. Passengers' arrival rate per hour.

The rest of the assumptions is scenario-specific and described in Section 5.

5 Simulation Experiments

In the scope of this paper, a journey of BT passengers in two time horizons, 2025 and 2035, was simulated in normal and ad-hoc disturbance conditions according to four scenarios defined in the first phase of the X-TEAM D2D project. The characteristics of these scenarios can be found in Table 2 and Table 3. Where it was possible, the operational characteristics of mobility services were adapted from the corresponding service operators (Connexxion, 2021; Electric Scooter Guide, 2021; EV Database, 2021; NV Nederlandse Spoorwegen, 2021). It is important to notice that only trains and buses operated on an on-schedule basis in these scenarios—the rest of the transport modes operated based on demand.

The simulated scenarios represent the following situations:

- In 2025, BT passengers use public buses to get to the city train station, from which they take a train to the airport. The next scenario, 2025d, implies that a disruption occurs when a passenger arrives at a train station and the trains no longer operate. To catch the flight on time, BT passenger has to get a taxi to reach the airport.
- In 2035, BT passengers use a form of pooled individual electric transport, such as an electric scooter (eScooter), to get to the landing site of eVTOL, from which they can take a direct flight to the airport. When a disruption occurs with eVTOLs in scenario 2035d, BT passenger has to take an electric taxi from the landing site to the airport.

Table 2. Overview of simulation scenarios for 2025.

Parameter	*2025*	*2025d*
Use case	B025	Bd25
Operation	Normal	Ad-hoc disturbance
Transport used	Bus, train	Bus, taxi
Travel distance 1st mode, km	Uniform(0,3)	Uniform(0,3)
Average travel speed 1st mode, km/h	18	18
Transfer time to 2nd mode, min	Uniform(1,15)	Uniform(1,15)
Travel distance 2nd mode, km	26	22
Average travel speed 2nd mode, km/h	65	60
Disruption location	-	Train station
Reaction to disruption time, min	-	Uniform(1,5)

Table 3. Overview of simulation scenarios for 2035.

Parameter	*2035*	*2035d*
Use case	B035	Bd35
Operation	Normal	Ad-hoc disturbance
Transport used	eScooter, eVTOL	eScooter, eTaxi
Travel distance 1st mode, km	Uniform(0,14)	Uniform(0,14)
Average travel speed 1st mode, km/h	27.5	27.5
Capacity 1st mode, passengers	1	1
Transfer time to 2nd mode, min	Uniform(1,15)	Uniform(1,15)
Travel distance 2nd mode, km	13	22
Average travel speed 2nd mode, km/h	200	60
Capacity 2nd mode, passengers	4	1

Disruption location	-	eVTOL landing site
Reaction to disruption time, min	-	Uniform(1,5)

The total travelled distance and total travel time were tracked across the simulation experiments to compare multimodal system performance in the presented scenarios. Each experiment simulated 25 hours of passengers travelling from a small European town to an international airport. The results of these experiments are discussed in Section 6.

6 Results

Experiments in scenarios 2025 and 2025d reflect the transportation network performance closest to the current state of multimodal connectivity. Scenarios 2035 and 2035d reveal some effects of emerging transport technologies integrated into existing transportation networks and replacing existing modes of transport. The results of simulation experiments are shown in Figure 6 and Figure 7.

Scenario 2025d resulted in a 14% shorter travel distance than in scenario 2025, as passengers could take the taxi directly to the airport. This difference, however, can be strongly dependent on the particular infrastructure layout. In this study, there is no fast train connection from the passengers' origin town, which results in longer travel. In 2035, such layout inefficiency is considered to be solved by establishing a direct air connection to the airport. Consequently, as can be seen in Figure 6, the travel distance was reduced by 26%.

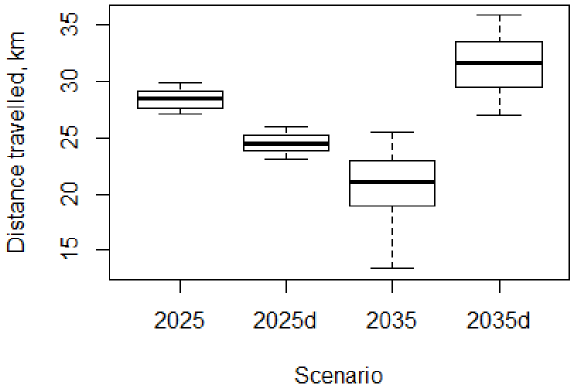


Figure 6. Travel distance statistics.

When comparing the distance travelled by business passengers in all four scenarios, it can be noticed from Figure 6 that the shortest distance corresponds to 2035. This result matches a scenario where eVTOL technology replaces road and railroad transport and provides the most direct connection to the airport. However, if eVTOL operations are disrupted and business passengers only learn about such disruption when they arrive at the landing site (scenario 2035d), relying on road transport for a quick solution to reach the airport creates a significant increase in travel distance – by 50% on average.

A similar effect can be observed in travel times. As shown in Figure 7, using a taxi in scenario 2025d allows reducing travel times by 5% on average. However, in 2035d, using an electric taxi in case of disruptions increases travel time by 40%, which means 8% longer travel than in scenario 2025d.

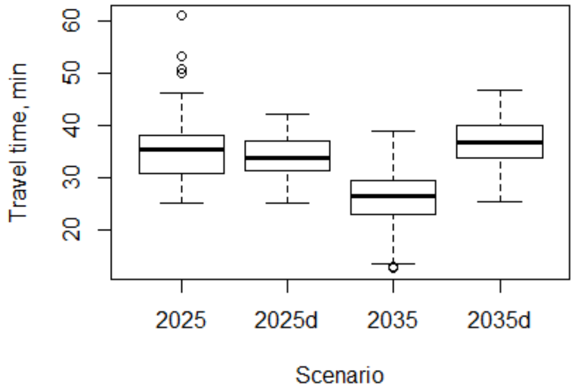


Figure 7. Travel time statistics.

To summarise, business travellers are expected to win significantly in travel time and distance if new technologies like 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.

7 Conclusions and Further Work

For seamless integration of existing and future transport technologies into an overall multimodal network with a high level of passenger service, the Concept of Operations (ConOps) have to be developed and validated. These concepts will ensure the inclusiveness and resilience of the future transportation network for all types of passengers. To define and validate such operational concepts, project X-TEAM D2D performed an extensive technological review for 2025, 2035, and 2050 and developed a simulation platform to assess the system performance.

In this paper, the authors used the framework to obtain preliminary results of the door-to-airport trip of business passengers. According to these initial results, emerging technologies such as individual electric transport and electric vertical take-off and landing aircraft can improve business passengers travel times in

2035 by 26%. However, considering the assumptions taken, if these passengers rely on on-demand road transport in case of disruptions, the resulting journey duration will be almost as long as in 2025.

In the simulated scenarios, it was assumed that the passengers noticed the disruption only when they arrived at the eVTOL port, which might not be the case if relevant journey planning systems are integrated sufficiently in 2035. As future work, the simulation framework will be expanded to reflect the state of the transportation networks in 2050. The developed ConOps will be integrated into the framework to perform their validation and evaluation. Furthermore, more performance indicators, visiting friends and families and other passenger profiles will be added to the framework to reflect better passenger-specific needs and goals of the multimodal systems in 2025, 2035 and 2050.

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