European Transport Research Review

ORIGINAL PAPER

Open Access

Urban Air Mobility demand forecasting: modeling evidence from the case study of Milan (Italy)

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Abstract
This paper presents the results of a demand forecasting study about the introduction of Urban Air Mobility (UAM) services in the metropolitan area of Milan (Italy). Demand forecasting is based on random utility mode choice models, which include factors related to the individuals' perception of vertical take-off/landing and low altitude flying over urbanized areas. The use cases of UAM services include airport shuttles, intercity air connections, and "air-taxis", i.e., UAM services for short-trips within the metropolitan area. Several scenarios have been considered based on the number of access points ("vertiports") and UAM fare levels. The results indicate that airport shuttles have a modal share of trips to/from airports (for both business and leisure) in a range of 2-5%. They resulted to be more attractive than air-taxis, which have a modal share in a range of 1-3%. Furthermore, the probability of choosing UAM services for intercity travels decreases with the distance and the time required for access/egress to/from the vertiports, whose catchment areas are dependent on the level of service provided by competing modes (notably the presence of good railway and highway connections).

Keywords UAM, eVTOL, Vertiports, Discrete choice analysis, Mode choice models, Urban mobility, Airport shuttles

1 Introduction

Urban Air Mobility (UAM) has been gaining increasing attention as a new mode for urban mobility and intercity (short haul) travels, enabling the use of the urban airspace for the mobility of both people and freight. While this might seem like a recent development, aerial point-to-point travel services using helicopters actually date back to the 1950s (see [1] for an historical review) and have been operated for over thirty year until they were discontinued due to safety concerns arising from mechanical failures and noise [2]. The novelty in UAM services stands in the wide range of new light vehicles, the so-called Vertical Take-Off and Landing (VTOL) aircraft, available for urban air operations. In fact, several vehicle manufacturers are currently developing advanced aircraft technologies for the first UAM commercial services, to provide efficient, sustainable, and time-saving alternatives to traditional ground transportation. UAM services require physical infrastructure to operate: they rely in fact on take-off and landing facilities known as vertiports [3]. One of the primary challenges lies in the identification of vertiports optimal locations to well-integrate these new services with existing ones.

Environmental sustainability is one of the main leverages for UAM promotion by worldwide companies and operators entered or interested in entering the market. Since electrification is generally seen as the future perspective for urban mobility (see for instance [4]),

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introducing electric air shuttles or electric air taxi services would have a double benefit: not only to favor a modal shift towards the aerial dimension reducing ground congestion, but also to encourage the use of vehicles with both zero tailpipe and low greenhouse gas emissions [5]. This is the reason why most of the VTOL manufacturers focused on battery electric aircraft, developing electric VTOL (eVTOL) prototypes to enter the market.

A preliminary market analysis based on information available on the web allowed to collect info on more than 90 VTOL prototypes (whose development stage ranged from the design to the flight certification process), identifying their main traits and characteristics. As shown in Fig. 1, eVTOL manufacturers are focusing on vehicles with different capacity (seats per aircraft), impacting on both vehicle dimensions and on-board space availability to locate battery packs: this will in turn influence the flight autonomy range. Particularly, bigger eVTOLs carrying three or more than three passengers (excluding the pilot) show a maximum flight range of 200 km on average, while smaller eVTOLs (i.e., two seats, one of which relating to the pilot) have a maximum average range of 90 km.

Therefore, the flight ranges of eVTOLs that are being developed do not seem to constitute a constraint for UAM operations in urban or suburban environments. Instead, there is still a debate, and several criticisms have arisen about the overall potential benefits following the introduction of UAM services [6, 7]. Despite them, several companies, usually in joint venture, announced their first UAM commercial operations in the short-medium period. For instance, Groupe ADP, Volocopter GmbH and RATP Group [8] expect to launch UAM services in Paris in 2024 together with the Summer Olympic games, AdR S.p.A., Atlantia S.p.A. and Volocopter GmbH [9] announced UAM airport shuttles operating in Rome during the Religious Jubilee in 2025, while S.E.A. S.p.A., F2i S.p.A. and Skyports [10] expect to manage aerial services in the Milan area starting from the "Milano Cortina" Winter Olympic in 2026. However, there is still uncertainty about how travelers will perceive these new services and which factors will be affecting users' intention-to-use UAM.

This paper aims to contribute to the ongoing debate about the feasibility of UAM services in urban areas, specifically by using simulations to understand how many travelers might choose new aerial airport shuttles, intercity air connections, and "air-taxis" (i.e., UAM services for short trips within the metropolitan area). Rather than focusing on individual preferences and travel behavior, the primary goal of this paper is to simulate different scenarios characterized by various assumptions about UAM services. The case study focuses on the Milan metropolitan area and the entire Lombardy Region in Italy, where the UAM modal share for different types of services has been estimated, and the factors affecting UAM choice probabilities have been analyzed.

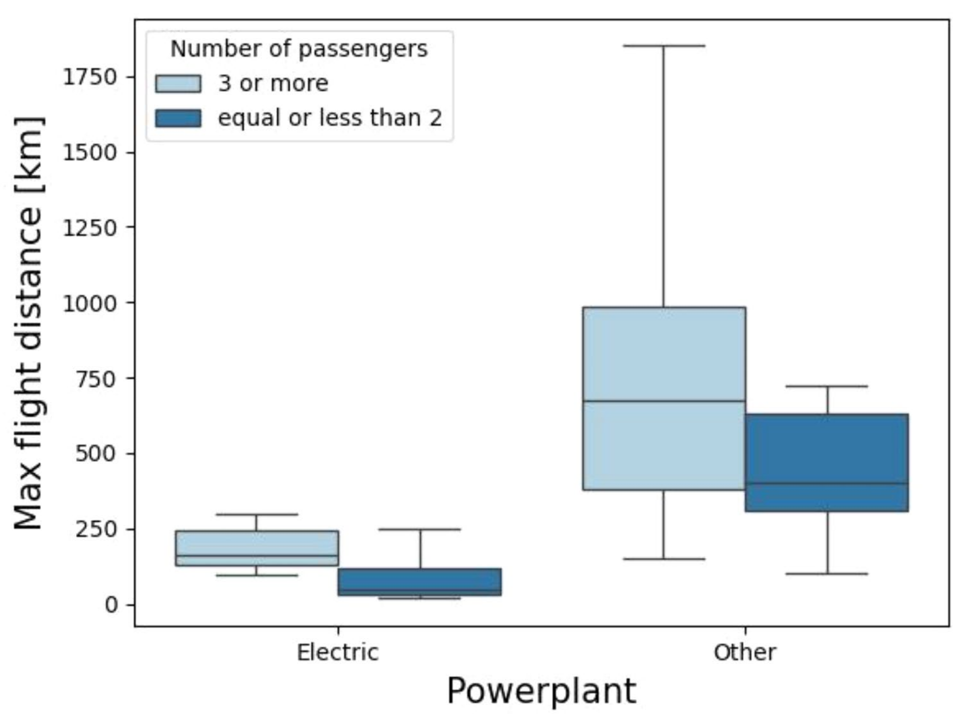

Fig. 1 VTOL maximum flight range versus powerplant (Electric or Other, including hybrid and gasoline powered) and passengers carried on board

The structure of the paper is as follows: Sect. 2 provides a literature review of UAM studies. Section 3 describes the data used and the modeling framework proposed for travel demand forecasting. The results obtained from the application to the case study are presented in Sect. 4 and discussed in Sect. 5. Finally, Sect. 6 provides concluding remarks along with perspectives for future research.

2 Literature review

The scientific literature on UAM has closely followed industry announcements about the commencement of eVTOL flying certification processes, primarily focused on the supply side and on aircraft technologies, i.e., propulsion, design and performances [11]. Many scholars focused on different propulsion technologies to be installed on-board these new aircrafts (see, for instance [12, 13]), , other research endeavors concentrated on their design and performances (see, for instance [14–16]), , while some others investigated the UAM concept of operations to identify potential operational constraints for the implementation or scale-up of such metropolitan aerial services (see [17]).

However, even if technology is the driving force behind such innovative services, the success of the overall UAM system is largely dependent on market demand. In scientific literature, several authors identified and discussed factors affecting users intention to use UAM (see [18]). Level of services factors, such as travel times and monetary cost, have been found to play a crucial role in shaping users' choices towards new aerial services [5, 19–22], but socio-economic variables such as gender [5, 22, 23], age [19–21], education status [19, 22, 23], employment status [20–22], income [5, 20, 22, 23] and also ethnicity [23] resulted to be important. Moreover, some scientific studies focused on travelers' personal attitudes such as safety and security concerns [20, 23], environmental awareness [22, 23], data privacy concerns [21, 22], affinity to automation [21, 22], affinity to online services or social media [22], but also on UAM expectations regarding service cost [5, 22], safety and security [5] and travel time reliability [23], exploring their significance for UAM intention to use.

Apart for the analysis of the factors affecting travelers' choices, one of the pivotal aspects to ensure the sustainability of the overall UAM ecosystem (also from the financial viewpoint) is the potential market share in relation to different UAM features (e.g., fare structure and levels, number of vertiports, ...) and use cases (e.g., intercity or intracity travels). Table 1 summarizes the studies in the literature on potential UAM demand, classifying them by the methodology adopted for demand forecasting and by use case considered.

Looking at the assumption on the UAM service type, two main clusters can be identified: some researchers [6, 24–26] focused on airport shuttle services connecting urban point of interest ("centralities") with airports, while others [27–29] analyzed air-taxi services for point-to-point travels (i.e., vertiport-to-vertiport) within the city or between cities. Moreover, other studies aim at assessing scenarios where the two types of service are integrated [5, 30, 31].

UAM tariffs will probably be one of the main factors influencing the adoption of these new aerial services and the assumption on its structure is another factor that differs quite a bit and varies between studies. Particularly, a distance-based fare structure is often assumed [24, 27, 29–31], sometimes complemented with a fixed base tariff per passenger [6, 26, 28] [25]. instead introduced a more complex structure consisting of a fixed base cost composed of two aliquots, i.e., landing per vehicle and travel per passenger, and a variable part depending on the flight distance. The extent of vertiport network may significantly influence UAM service accessibility, spatial capillarity and in turn its attractiveness: usually (see for instance [5, 29–31]) more realistic scenarios are implicitly assumed, including only a few number of vertiports in the study area and therefore serving a limited number of origin-destination relations.

All the abovementioned factors have an impact on demand forecasts and on UAM modal share estimates. It is particularly worth noting that, on average, studies in the literature found UAM to be attractive for less than 5% of travelers, with lower bounds less than 1% (see for instance [6, 28]). However, there are also researchers stating huge UAM attractive potential for specific demand segments (for instance, 71% UAM modal share for high-income households, as reported in [27]). This study aims at contributing to the existing literature presenting a simulation related to the Milan metropolitan area case study and considering the overall Lombardy Region as study area, providing information regarding UAM service attractiveness and discussing factors affecting UAM choice probability. Unlike other research in the literature, this study provides detailed analysis for three different UAM use cases that differ in spatial patterns, i.e., airport shuttles, intercity air connections, and air-taxis.

3 Methodology

The methodological approach adopted in this study is schematically depicted in Fig. 2.

The first step consists of the assumption on the vertiport locations that affect UAM travel times and costs, also including the access/egress travel phases to/from the vertiports. These have been estimated through a multimodal transport supply model of the study area, consisting of 112,120 nodes and 319,728 directed links. The road

Table 1 Worldwide studies on potential UAM demand, together with main UAM service features and network assumptions

Year of publication	Study Area			Methods for demand forecasting	UAM assumptions			Forecasted UAM modal share	Source
	Continent	Country / Nation	Cities		Service Type	Price per person and distance	Number of vertiports		
2023	Asia	South Korea	Seoul metropolitan area	Scenario simulation through a Macro-simulation transport model	Air-taxis and airport shuttles	4.02 USD/mile, 2.68 USD/mile, 1.34 USD/mile for initial, growth, and maturity period respectively	9	0.3% for air-taxis; 10.3% for airport shuttles (UAM price scenario: 2.68 USD/mile)	[24]
2022	Asia	South Korea	Seoul	Scenario simulation through a mode choice model (Multinomial Logit and Mixed Logit)	Air-taxis and airport shuttles	n.a.	11 + 2 at the airports	n.a.	[5]
2021	North America	U.S.A., California	Northern California cities	Scenario simulation through a mode choice model (Mixed Logit)	Air-taxis	1.20 USD/mile in the High demand scenario; 1.80 USD/mile in the Low demand scenario	200 in the High demand scenario; 75 in the Low demand scenario	Between 2% and 71%, depending on the demand segment (i.e., low-, mid-, and high-income households)	[25]
2021	North America	U.S.A., California	Los Angeles	Scenario simulation through mode choice model (Mixed Logit)	Airport shuttles	Ranging from 1.40 USD/mile to 3.00 USD/mile (75 vertiport scenario)	50, 75, 100, depending on the scenario	Between 4.9% and 2.4%, depending on the USD/mile assumption (75 vertiport scenario)	[26]
2021	Europe	Germany	Upper Bavaria Region, including Munich	(incremental) Nested Logit + Agent based scenario simulation	Airport shuttles	5€ fixed + 2€/km	74	0.61%	[6]
2021	North America	U.S.A., South Dacota	Tampa Bay area	Scenario simulation through an optimization model	Air-taxis	30 USD fixed + 2 USD/km	30	0.20%	[27]
2021	North America	U.S.A., Texas	Dallas-Fort Worth metro area	Scenario simulation through a mode choice model (Multinomial Logit)	Airport shuttles	Landing cost per vehicle: 20 USD + Base cost per passenger: 15 USD + Cost per Mile: 2 USD	50	4%	[28]
2019	Europe	Swiss	Zurich area	Agent based scenario simulation	Air-taxis and airport shuttles	Ranging from 0.6 CHF/km to 1.8 CHF/km	10	n.a.	[29]
2018	North America	U.S.A., Florida	Sioux Falls	Agent based scenario simulation	Air-taxis	Three times that of cars	10	n.a.	[30]
2017	North America	U.S.A., California	Northern California cities	Scenario simulation through mode choice model (Conditional Logit)	Airport shuttles	Fixed (ranging from 0 to 15 USD) + Variable (ranging from 1.46 to 0.77 USD/mile)	400, 1000	Between 0.27–20%, depending on the UAM fare structure and in the "more realistic", as defined by the authors, scenarios	[31]

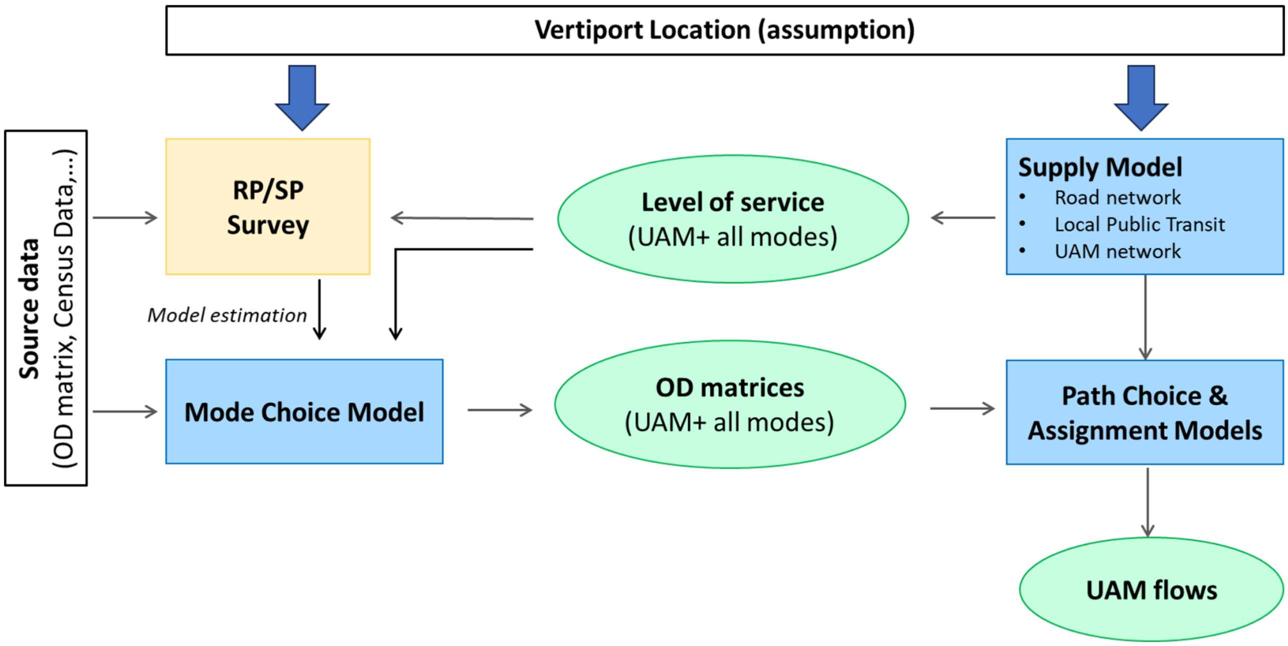

Fig. 2 Flowchart describing the methodological approach adopted in this study

Table 2 Number of lines, number of stations/stops and overall length related to Public Transport services included in the Lombardy Region multimodal transport model

Type of service	Number of Lines	Number of Stations/ Stops	Overall Length [km]
Rapid regional rail	11	144	2,328
Regional rail	30	341	3,742
Airport shuttle rail	2	8	132
Suburban rail	15	160	1,063
Underground	5	161	275
Tram	18	610	219
Bus and Trolleybus	139	3,966	3,565
Total	**220**	**5'390**	**11'324**

network model was extracted from the OpenStreetMap[1] dataset, including five different link types (i.e., motorway, highways, primary roads, secondary roads, tertiary roads).

The public transportation network model was based on the georeferenced data and timetables contained in the General Transit Feed Specification[2] dataset of different Public Transport operators serving the area: it includes railway, underground, tram, bus and trolleybus services (see details in Table 2).

The UAM network consists of N nodes (i.e., the vertiports) and $N \cdot (N-1)$ directed links (i.e., UAM service routes), where N varies depending on the simulated scenario.

The daily origin-destination (OD) trip matrices have been taken from the Lombardy Region open dataset[3]. The travels from/to the airports of Milan have been estimated based using the airport market survey data, including the number of daily access/egress travels to and from Linate (LIN) and Malpensa (MXP) airports, and their aggregate geographical distribution by travel purpose.

3.1 RP/SP survey data collection campaign

A mixed Revealed Preference (RP) and Stated Preference (SP) survey has been carried out to get information about travelers' current travel choices and attitudes toward UAM services to estimate the mode choice models. The survey was distributed via Computer Assisted Personal Interviews (CAPI), using tablets with both Italian and English language options. Each respondent held a single tablet to complete the questionnaire and was assisted by an interviewer ready to intervene in case of any problems. Interviewees were selected at random within the Milan metropolitan area in the major transport hubs and prominent attractions, including airports (MXP and LIN), railway stations (Milano Cadorna, Milano Centrale, Milano Rogoredo, Monza), bus terminals with parking facilities for interchanges (Lampugnano, Famagosta), as well as in landmarks in the Municipality of Milan, such as City Life and Gae Aulenti Square. The random sampling strategy was defined to ensure a balance between the number of interviews conducted each day of the week (i.e., the

[1] https://www.openstreetmap.org/.

[2] https://database.mobilitydata.org/.

[3] https://www.dati.lombardia.it/Mobilit%C3%A0-e-trasporti/Matrice-OD2030-Passeggeri/sht7-5jd5.

percentage of interviews collected on Thursdays matched those collected on Fridays, Saturdays, etc.), between weekdays and holidays (i.e., the percentage of interviews collected on holidays was proportional to the percentage of yearly holidays according to the Italian calendar), and between different times of the day. It is important to note that interviews were conducted from 8:00 am to 9:00 pm; therefore, individuals outside this time frame were not interviewed. Respondents for the sample were selected at regular intervals of 20 min among those entering main entrances or exiting main exits of the locations where the interviews were conducted. The questionnaire guaranteed complete anonymity and fully adhered to the European General Data Protection Regulation. It was exclusively administered to individuals of legal age in accordance with the Italian legislation, without any discrimination.

The RP section featured sixteen questions and focused on creating a respondent profile encompassing different factors, including age, gender, education level, employment status, gross annual income, household composition, availability of a driving license and/or private vehicle for daily travels. Additionally, questions related to the specific travel the respondent was taking, together with her/his mobility habits, were included: these allowed to collect information on travel origin and destination, chosen mode of transportation, trip duration and cost, trip purpose, trip frequency, availability of travel expense refund and number of people they usually travel with. Right after this first section, participants were presented with a brief video, showing the UAM service and its entire travel experience. Finally, interviewees were invited to take part in the SP experiment. This was constructed following the efficient design approach [32, 33] Interviewees made choices in up to six different situations, customized according to information collected in the RP section of the questionnaire, namely trip duration — over (O) or under (U) 60 min — travelling alone (I) or with others (C), and the availability (or lack thereof) of a car as an enabler for the car modal alternative in the choice situations. Therefore, eight different designs have been generated. It is important to note that, to streamline interview duration, these designs were separated by blocks, each comprising six choice situations. Only one block per respondent has been proposed. In this way, the efficient designs were split into smaller sets, guaranteeing balanced attribute levels within each block and ensuring that the choice situations were evenly distributed across the respondents. In each choice situation, respondents compared and chose among four modal alternatives: car, taxi, public transport (PT), and UAM. Those who declared not having a car chose from three options. A pilot survey was carried out to test respondents' reactions and understanding of the questions. This survey identified the most significant factors influencing mode choice, such as access/egress time, waiting/boarding time, in-vehicle time, and monetary cost. In the SP choice situations, time and cost levels for car, taxi, and public transport modal alternatives were varied based on the existing average origin-destination level of service characteristics of the Milan area transport system. The average modal attributes related to the case study were estimated using the multimodal transport supply model of the study area, which is briefly described in the introduction of Sect. 3 of this manuscript. For UAM, the in-vehicle times and costs were tailored around estimated values, assuming eVTOL technical specifications (cruise speed of 150 km/h) and unit service fares of 3.5 €/km, in line with values reported by [27]. Table 3 shows a summary of the modal alternatives, together with their level of service attributes and the levels of variation in each design.

Table 3 Attribute values for Stated Preferences experiment. I: travelling alone; C: travelling with a party; O: over 60 min; U: under 60 min. Source: [34]

Alternatives	Attributes	Values				Unit
		I - O	I - U	C - O	C - U	
Car (if available)	In-Vehicle time	60, 75, 90	30, 45, 60	60, 75, 90	30, 45, 60	min
	Monetary cost	20, 25, 30	10, 15, 20	10, 15, 20	5, 10, 15	EUR €
Taxi	Waiting/Boarding time	5, 10, 15	5, 10, 15	5, 10, 15	5, 10, 15	min
	In-Vehicle time	60, 75, 90	30, 45, 60	60, 75, 90	30, 45, 60	min
	Monetary cost	60, 75, 90	30, 45, 60	30, 40, 50	15, 25, 35	EUR €
Public transport	Access/Egress time	10, 15, 20	5, 10, 15	10, 15, 20	5, 10, 15	min
	Waiting/Boarding time	10, 15, 20	5, 10, 15	10, 15, 20	5, 10, 15	min
	In-Vehicle time	60, 75, 90	30, 45, 60	60, 75, 90	30, 45, 60	min
	Monetary cost	10, 15, 20	2, 5, 8	10, 15, 20	2, 5, 8	EUR €
UAM	Access/Egress time	10, 15, 20	5, 10, 15	10, 15, 20	5, 10, 15	min
	Waiting/Boarding time	5, 10, 15	5, 10, 15	5, 10, 15	5, 10, 15	min
	In-Vehicle time	20, 25, 30	10, 15, 20	20, 25, 30	10, 15, 20	min
	Monetary cost	150, 200, 250	90, 120, 150	75, 100, 125	40, 60, 80	EUR €

The data collection spanned three months, running from late 2021 to early 2022, and resulted in the acquisition of more than 2,145 interviews. Of these, 1,127 were classified as pertaining to airport-related journeys, while the remainder were categorized as city trips. The average survey duration was 9.7 min (with the first quartile of the time distribution at 8.5 min and the third quartile at 11.7 min). The percentage distribution of collected interviewees by location has been reported in Table 4 where it can be noted that almost half of the interviews were carried out at the airports of Milano Malpensa and Milano Linate, that are included as the hubs of the metropolitan and regional UAM services in the simulated scenarios (see Sect. 4.1). The breakdown of the sample according to socio-economic factors is included in Table 5. It can be noted that the sample is well-balanced according to gender, whereas middle age groups (i.e., from 35 to 54 years old) and employed are overrepresented in the sample with respect to average population distribution in the Lombardy Region. The differences between the sample and population statistics should be understood as a direct result of the on-site random sampling approach used to select interviewees. This method reflects the actual characteristics of the people frequenting the locations where the data collection campaign took place, primarily individuals of working age traveling to and from the city of Milan. It is worth noted that the sample includes also a small fraction of very-high income travelers (i.e. average annual income above 120.000 euro) that resulted to be a significant variable in the choice of UAM services.

3.2 Mode choice models

Only the SP part of the database has been used for discrete mode choice modelling estimation, relying on the assumptions of random utility theory [35]. It has been assumed that an individual n has declared preferences on each transport mode j on different choice situations s, that can be measured through the perceived utility function U_{nsj}: this can be set equal to the sum of a systematic utility component V_{nsj} and a random residual ϵ_{nj} as reported in Eq. 1 (where the V_{nsj} function is assumed as a weighted by β_{nk} linear combination of k explanatory variables x_{nsj}).

$$U_{nsj} = V_{nsj} + \epsilon_{nsj} = \sum{}_k(\beta_{nk} \cdot x_{nsjk}) + \epsilon_{nsj} \quad (1)$$

A Multinomial Logit (MNL) discrete choice modelling specification has been adopted, using panel data to consider the non-independence of the observations associated with the same interviewee. The models used for the application presented in this paper (Table 7) are MNL models adapted from the Mixed Logit (ML) models estimated in [34], by constraining the coefficients of in-vehicle travel times (IVTT) and monetary costs (MC) to estimates that yield values of travel time savings (VoTT) equal to the median values of the VoTT distributions (Table 6).

Indeed, in [34] it was found that the parameters estimated using the MNL specification resulted in elasticities that were unrealistic and VoTT savings not in line with the literature. Applying the ML models was too complex and beyond the scope of our analysis, i.e. to explore the potential impacts of UAM on travel demand in the metropolitan area of Milan (Italy). Therefore, in the application to the case study, we opted to use a new MNL specification in which the parameters for in-vehicle time and monetary costs were constrained to get VoTT savings in Table 6, while the other parameters were estimated using Maximum Likelihood. These models were implemented in the PTV VISUM simulation software and applied to the study area. In both models, the systematic utility function incorporates several mode-specific level of service variables:

- IVTT: In-vehicle travel time (minutes);
- AET: Total access and egress time (minutes);
- WBT: Total waiting and boarding time (minutes):
- MC: Total monetary cost per person (€); it is worth specifying that an interaction term with the MC value is included for the business travel dummy variable, which is 1 if the interviewee is traveling for business purposes and 0 otherwise.

It is worth mentioning that, to account for different values of travel time (i.e., the ratio between the IVTT and MC beta estimates), we adopted model specifications with both mode-specific time and cost parameters. This approach is feasible given the labeled nature of the SP experiment, where modal alternatives are explicitly named as CAR, PT, TAXI, and UAM (see [36–38] for other examples). The systematic utility function also accounts for individual socio-economic characteristics

Table 4 Percentage distribution of collected interviews by location

Location type	Name	% of interviewees
Transport Hubs	Milano Malpensa Airport	31%
	Milano Linate Airport	21%
	Milano Central Station	11%
	Milano Cadorna Station	6%
	Milano Rogoredo Railway Station	6%
	Monza Railway Station	3%
	Lampugnano bus terminal	4%
	Famagosta bus terminal	4%
Turistic places	"Palazzo Lombardia" Area	8%
	"Gae Aulenti" Area	3%
	"City Life" Area	3%

Table 5 Socio-economic and trip characteristics of the sample

Variable	Collected interviews (Sample size = 2'145)		Lombardy Region population
	n	%	%
Gender			
Male	1168	54.5	49.1
Female	977	45.5	50.9
Age group			
Less than 25	126	5.9	22.8
25 to 34	336	15.7	10.5
35 to 44	646	30.1	12.6
45 to 54	692	32.3	16.3
55 to 64	258	12.0	14.6
More than 64	87	4.1	23.2
Employment status			
Employed	1540	71.8	51.6
Student	132	6.2	7.4
Unemployed	100	4.7	3.6
Retired	184	8.6	37.3
Other	189	8.8	
Educational level			
None	0	0.0	3.6
Elementary school diploma	16	0.7	14.4
Middle school diploma	78	3.6	28.4
High school diploma	991	46.2	37.3
Bachelor's degree	327	15.2	16.3
Master's degree	647	30.2	
PhD	86	4.0	
Gross personal annual income			
Equal or lower than 120 k€	2054	95.8	n.a.
Higher than 120 k€	91	4.2	n.a.
Trip purpose			
Business	494	23.0	n.a.
Other	1651	77.0	n.a.
Spatial trip pattern			
From/to airport trip	1127	52.5	n.a.
Metropolitan	1018	47.5	n.a.
RP mode			
Private Transport	628	29.3	64.5
Public Transport	1024	47.7	19.6
Other	493	23.0	15.9
Origin-Destination			
To/From Milan	1338	62.4	20.9
Other	807	37.6	79.1
Travel Distance			
Less than 5 km	253	11.8	10.0
5–10 km	402	18.7	28.7
10–20 km	327	15.2	31.4
20–50 km	604	28.2	17.7
50–75 km	409	19.1	5.8
More than 75 km	150	7.0	6.3

Statistics about the Lombardy Region population are author's elaboration based on ISTAT census data (accessible at: https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie/) and on daily OD trip matrices provided by the Lombardy Region (accessible at: https://www.dati.lombardia.it/Mobilit%C3%A0-e-trasporti/Matrice-OD2030-Passeggeri/sht7-5jd5)

Table 6 Adopted Values of Travel Time (VoTT) savings for from/to airports and metropolitan trips. Source: [34]

	Non-Business trips		Business trips	
	To/from Airport trips	Metropolitan trips	To/from Airport trips	Metropolitan trips
Car	21 €/h	4 €/h	32 €/h	6 €/h
PT	6 €/h	9 €/h	8 €/h	10 €/h
Taxi	44 €/h	26 €/h	64 €/h	39 €/h
UAM	48 €/h	34 €/h	69 €/h	44 €/h

through a linear combination of four mode-specific variables:

- Age (>45): Dummy variable equal to 1 if the respondent is over 45 years old, 0 otherwise;
- Annual Income (>120 k€): Dummy variable equal to 1 if the respondent's personal gross annual income exceeds 120,000 €, 0 otherwise;
- Employment Status (employed): Dummy variable equal to 1 if the respondent is employed, 0 otherwise.

In both models, CAR is used as the baseline alternative. Consequently, all socio-economic dummy variables and Alternative Specific Constants (ASCs) have to be interpreted in relative terms. The adopted parameters, along with statistical modeling details from the estimation, are presented in Table 7.

Each model has been estimated with a sample of more than 1'000 interviews and over 5'500 observation each. The direct elasticity of the mode choice probability with respect to travel time ranges from –0.3 to -0.9, depending on the mode and the origin-destination distance. Similarly, the elasticity with respect to travel cost ranges

Table 7 Multinomial logit models for both from/to airports and metropolitan trips. Significance level: *** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.10$

MNL Parameters	From/to airports trips			Metropolitan trips		
	Estimate	t-statistic		Estimate	t-statistic	
Alternative specific constants						
PT	-0.1922	-1.57		0.5159	5.20	***
Taxi	-0.5171	-9.64	***	-1.7188	-25.29	***
UAM	0.2309	2.70	***	0.4619	4.16	***
Level of Service variables						
IVTT Car	-0.0180	-	-	-0.0050	-	-
IVTT PT	-0.0050	-	-	-0.0057	-	-
IVTT Taxi	-0.0248	-	-	-0.0074	-	-
IVTT UAM	-0.0145	-	-	-0.0136	-	-
AET PT	-0.0405	-7.26	***	-0.0079	-2.06	**
AET UAM	-0.0178	-3.22	***	-0.0185	2.74	***
WBT PT	-0.0186	-3.37	***	-0.0098	-1.95	*
MC Car	-0.0510	-	-	-0.0800	-	-
MC Car: Business	0.0170	-	-	0.0260	-	-
MC PT	-0.0520	-	-	-0.0370	-	-
MC PT: Business	0.0130	-	-	0.0020	-	-
MC Taxi	-0.0340	-	-	-0.0170	-	-
MC Taxi: Business	0.0107	-	-	0.0055	-	-
MC UAM	-0.0180	-	-	-0.0240	-	-
MC UAM: Business	0.0054	-	-	0.0056	-	-
Socio-Economic variables						
PT: Age (>45)	-0.3012	4.55	***	0.2476	4.41	***
UAM: Age (>45)	-0.2007	-3.01	***	-	-	-
PT: Annual income (>120 k€)	0.6997	-3.40	***	-0.7894	-4.38	***
Taxi: Annual income (>120 k€)	0.6075	2.50	***	-	-	-
UAM: Annual income (>120 k€)	1.3627	8.40	***	-	-	-
PT: Employment status (employed)	-0.2498	-3.80	***	-	-	-
UAM: Employment status (employed)	-	-	-	0.3488	4.23	***
Sample size	1'127			1'018		
# Observations	5'617			5'732		
Log-likelihood at observed shares (C)	-7'246			-7'946		
Log-likelihood final (β)	-6'661			-5'789		
McFadden's Rho-squared	0.08			0.07		

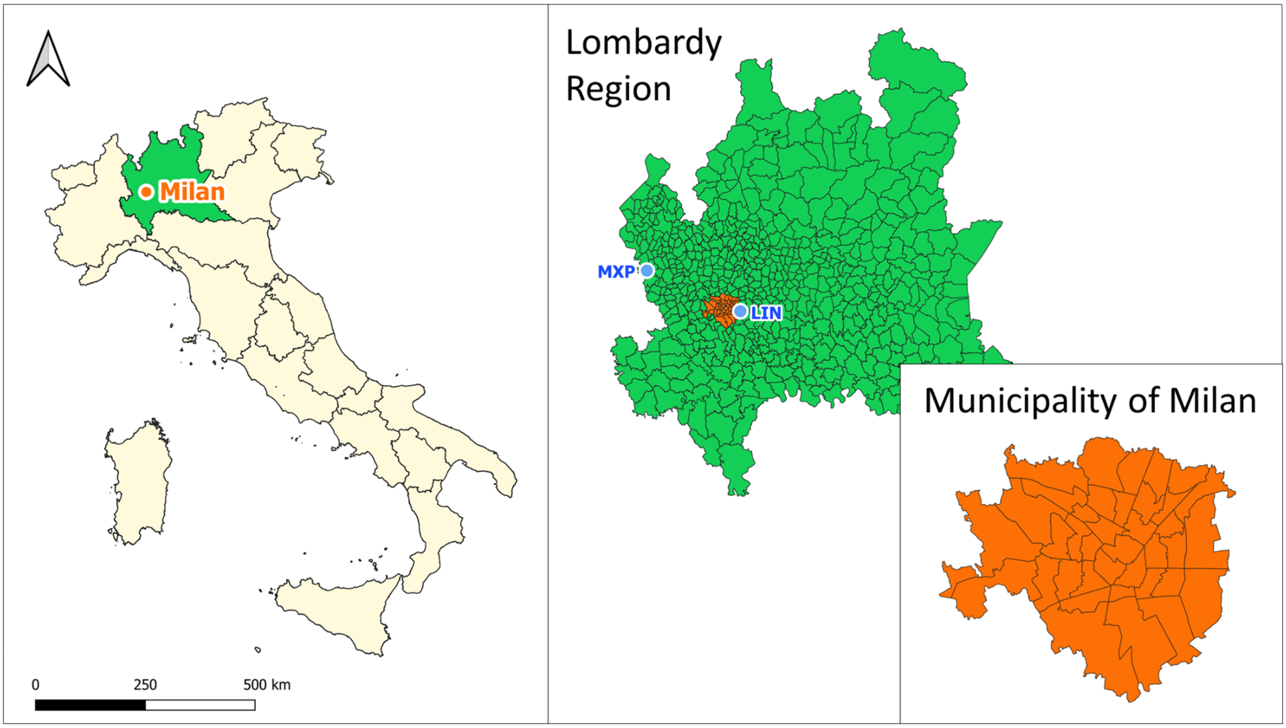

Fig. 3 Study area identification and zoning

from −0.5 to -1.1, also varying by mode and origin-destination distance. For the interpretation of the modeling results along with a comparison to estimates in the literature, readers are referred to [34].

The mode choice models have been subsequently implemented to simulate the mode choice in different scenarios and estimate the OD matrices to be assigned to the multimodal network.

3.3 Assignment models

Assignment models simulate the interaction between transportation travelers' choices (demand) and transportation supply performances. They typically embed the simulation of path choices for different modes of transport and allow the estimation of flows on individual links in the multimodal transportation network. For all the simulated modal alternatives, given the daily analysis period, generalized minimum-cost path assignment algorithms have been adopted [39].

4 Application to the milan case study

The proposed methodology has been applied to the case study of Milan. The study area includes the entire Lombardy Region (see Fig. 3) that counts approximately 10 million inhabitants, being the most populated Italian region and the one that produces over a fifth of the Italian national Gross Domestic Product. The study area has been divided into 613 traffic analysis zones: 571 are municipalities (or an aggregation of them, especially in rural or peripheral areas), 2 are LIN and MXP airports, while the remaining 40 are related to the Municipality of Milan, where a detailed zoning at zip code level has been introduced.

Table 8 Assumptions related to UAM services with reference to different scenarios

# Scenario	1	2	3	4
Service type	UAM airport shuttles, intercity air connections, and air-taxis			
Price per person and distance unit	3.50 €/km (min 60€)	3.50 €/km (min 60€)	3.25 €/km (min 50€)	3.00 €/km (min 45€)
Number of vertiports	4 (including 2 airports)	6 (including 2 airports)	10 (including 2 airports)	17 (including 2 airports)

4.1 Scenarios: vertiport location and assumptions on UAM services

Four different scenarios have been simulated (Table 8): all of them consider both UAM airport shuttle services, intercity air connections, and air-taxis, but they differ by the assumptions on the number of operating vertiports and the origin-destination (OD) pairs connected by UAM services (both increasing from Scenario 1 to Scenario 4), and on the UAM fares (decreasing from Scenario 1 to Scenario 4).

The number of operating vertiports varies from four in Scenario 1 to seventeen in Scenario 4, two of which are vertical takeoff and landing infrastructure located in LIN

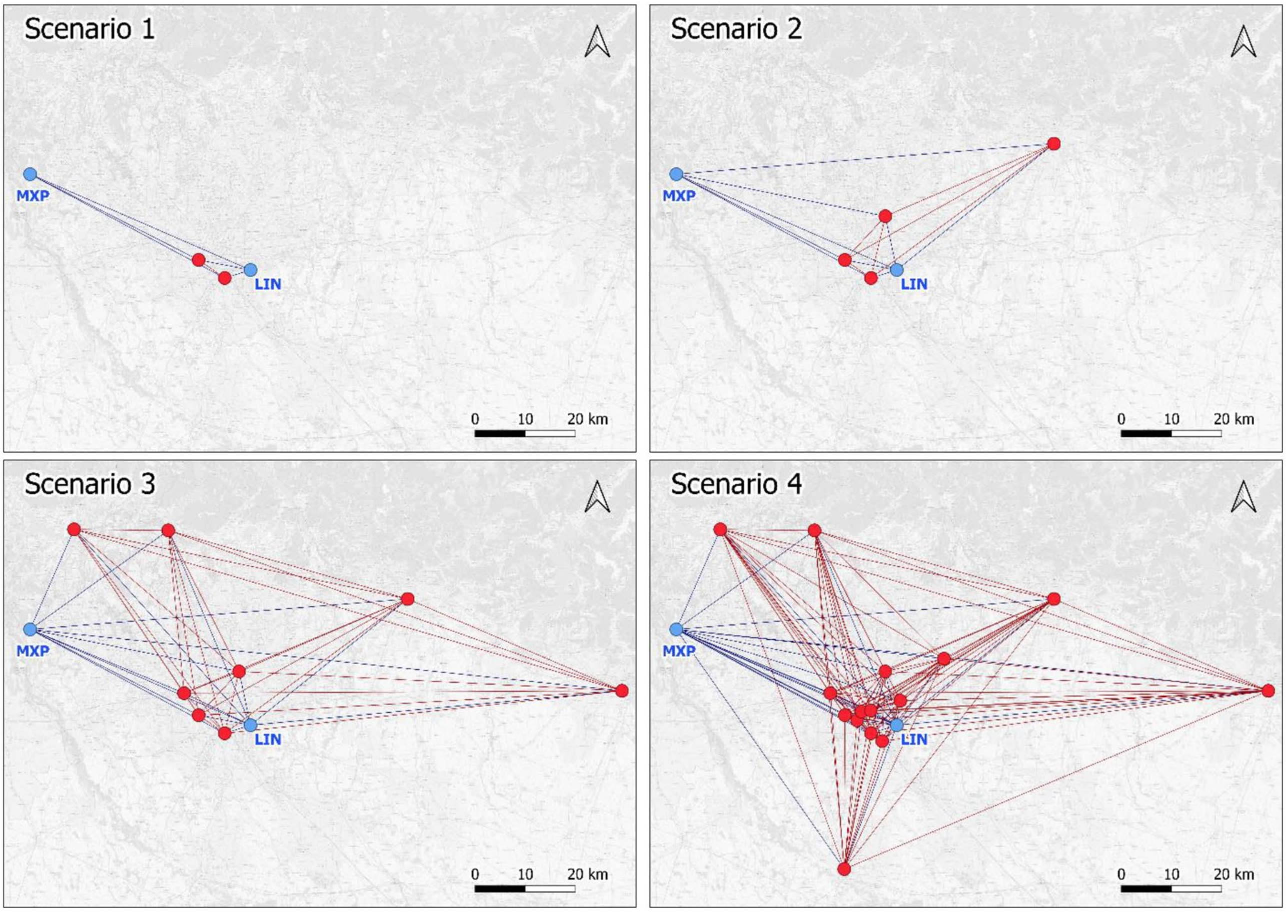

Fig. 4 Assumptions on UAM service network in different scenarios

and MXP airports. Feasible vertiport locations resulted from a desk analysis, combining territorial features (such as, jobs densities, residents' densities, touristic locations), transport features (such as proximity to transport hubs or transport nodes), and spatial constraints on land availability. As shown in Fig. 4, in all scenarios it is assumed that vertiports are connected to each other through direct UAM services.

The UAM fare is based on the travelled distance and varies from 3.50 €/km-person in Scenario 1 to 3.00 €/km-person in Scenario 4, with a minimum ticket cost of 60 €/person and 45 €/person respectively.

The rationale behind the assumptions of the simulated scenario is to mimic a possible evolution of UAM service in the study area. Moving from Scenario 1 to Scenario 4, we assumed an increase in the number of vertiports, which corresponds to a broader diffusion of the service and, accordingly, a reduction in the average fare of UAM services. This is similar to trends observed in new transport markets, such as high-speed rail. These assumptions have been validated with experts from the industry and companies entering the UAM market, including service operators, planners, vertiport developers, and public authorities (e.g., regulators).

Table 9 Overall UAM modal shares with reference to both different service types and different scenarios

# Scenario	1	2	3	4
UAM airport shuttles modal share	0.6%	1.6%	1.9%	2.1%
UAM intercity connections and air-taxi modal share	0.1%	0.1%	0.2%	0.2%

4.2 Results analysis

Overall UAM average modal shares with reference to different service types and different scenarios are reported in Table 9. It can be noted that airport shuttle services result to be more attractive than other services (including intercity air connections and air taxis): modal share of the firsts ranges from 0.6% in Scenario 1 to 2.1% in Scenario 4, while those related to the latter are lower than 0.2% in all the simulated scenarios.

For Scenario 4, the UAM choice probability has been analyzed by origin-destination (OD) pair and by UAM type of service as function of the flying distance and access/egress (A/E) time to/from vertiports. Simulation

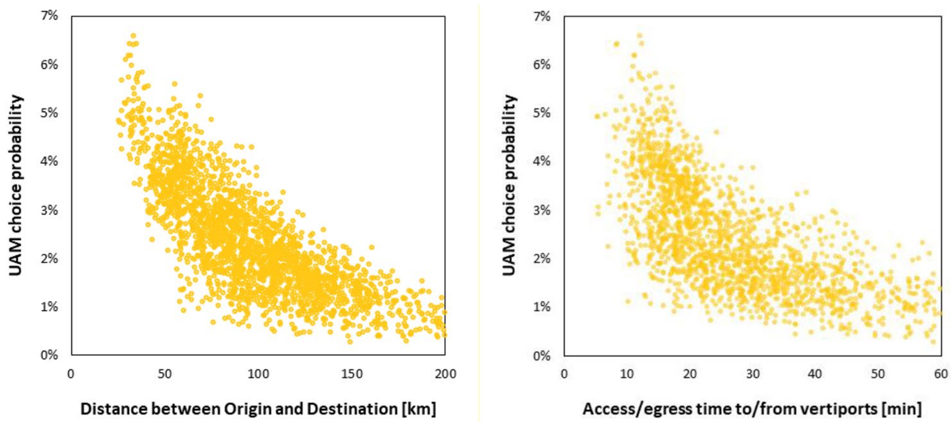

Fig. 5 UAM choice probability for intercity air connections, as function of OD flying distance (graph on the left) and of access/egress time to/from vertiports (graph on the right)

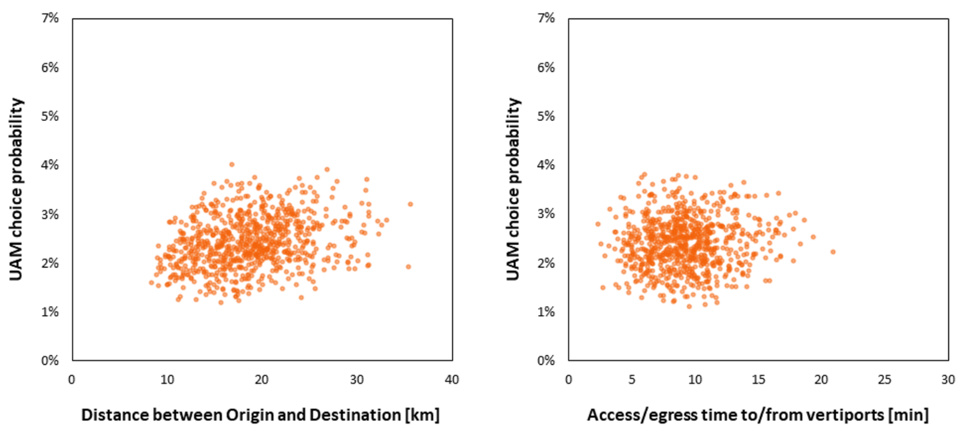

Fig. 6 UAM choice probability for air-taxi services, as function of OD flying distance (graph on the left) and of access/egress time to/from vertiports (graph on the right)

results for intercity travels show that the probability of choosing UAM services decreases with the distances (Fig. 5).

A/E time to/from vertiports do also affect UAM choice probabilities, that resulted to be higher if travelers' origins and/or destinations are close to vertiports and rapidly tend to zero when A/E time increases over 20 min.

For UAM air-taxi services it could be firstly observed that choice probabilities are lower than those for intercity travels (Fig. 6). Moreover, simulation results show no clear trends of UAM choice probailities neither with distance nor with A/E time. This might depend on the fact that UAM travel times are rather similar on the competing modal alternatives and greater OD distances do not sistematically correspond to longer travel times. In fact, public and private OD travel times depend more on the presence of underground or railway connections, as well as road arterials, than on the OD distance.

Finally, Fig. 7 shows simulation results for UAM airport shuttle services. Despite points in both graphs are quite scattered also for this use case, an overall inverse proportionality between UAM choice probability and origin-destination flying distance can be observed.

Figure 8 shows vertiport catchment areas for intercity connections and air-taxi services, defined as the zones where the average probability of using UAM to reach other zones of the study area is higher than 1‰ (75th percentile of the distribution). It can be observed that vertiports catchment areas vary in size and shape depending on factors like transportation infrastructure provision and the UAM connections available at each vertiport. Moreover, vertiport catchment areas are larger where the level of service (including travel time and frequency) of the competing modes decreases (e.g. rural areas). As an example, it is worth mentioning the difference between the catchment areas of vertiports located in the provinces and those located in the metropolitan area of Milan: the former extend well beyond the administrative borders of the provinces, the second ones are limited to the areas close to the vertiports due to the competition with public transport or road transport alternatives.

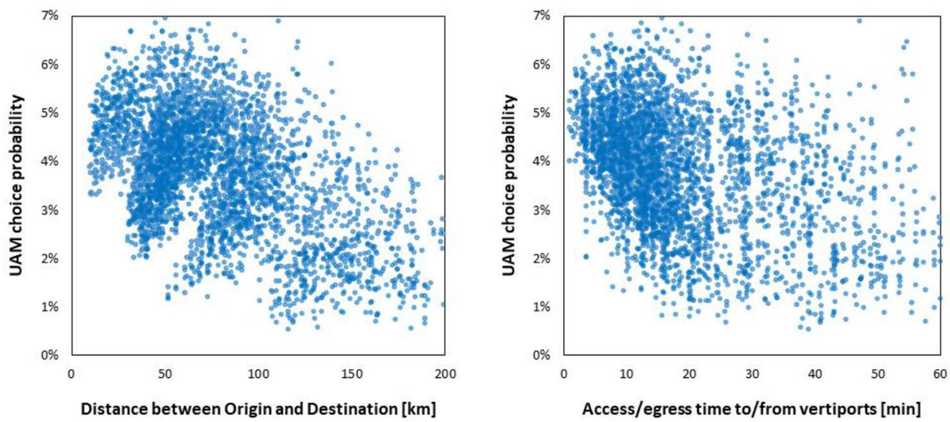

Fig. 7 UAM choice probability for airport shuttle services, as function of OD flying distance (graph on the left) and of access/egress time to/from vertiports (graph on the right)

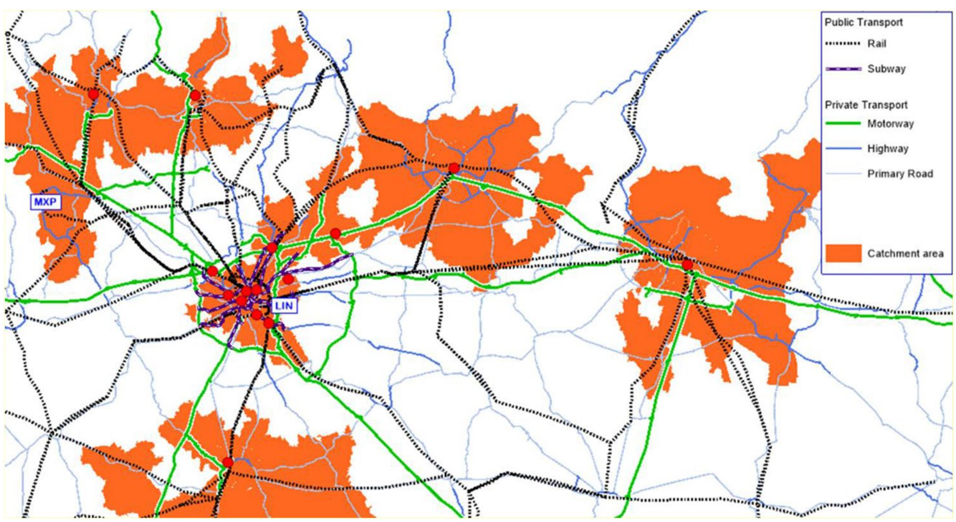

Fig. 8 Average on all the OD pairs UAM choice probability for intercity air connections and air-taxi services

The analysis of vertiport catchment areas for airport shuttle services have been distinguished for UAM connections to/from MXP airport and to/from LIN airport. These are the two major airports serving the city of Milan and they differ in terms of transport accessibility mainly due to their geographical locations. In fact, MXP is located to the northwest of Milan, approximately 45 km from the city center, while LIN is the Milan city airport (located approximately 7 km east of Milan) accessible by public transport (underground and buses).

Figure 9 shows the vertiport catchment areas of Malpensa Airport (MXP) espressed as the zones with UAM choice probabilities to/from the airport higher than 4% (75th percentile of the distribution). It can be noted that zones located at distances less than 30–35 km from the airport are captive areas for other transport modes. On the other hand, for zones between 30 km and 60 km from MXP, UAM is more competitive (i.e. modal share is higher than 4%).

Figure 10 shows vertiport catchment areas for UAM airport shuttles to/from Linate airport (LIN). It can be noted that the catchment area includes the west sector of Milan not directly connected by metro and whose arterials connections suffers from recurrent congestion, making UAM services competitive.

The extension of the vertiport catchment areas is a mayor determinant for potential UAM demand. In Fig. 11, UAM vertiport-to-vertiport passengers' volumes are depicted, showing that the highest volumes are related to UAM services to access or egress airports, and specifically to/from MXP airport that is less accessible by competing transport modes, and that could benefit more from the introduction of UAM services.

5 Discussion

The simulation results concerning the case study of Milan indicate that travelers find UAM airport shuttles more attractive than intercity air connections or air-taxis,

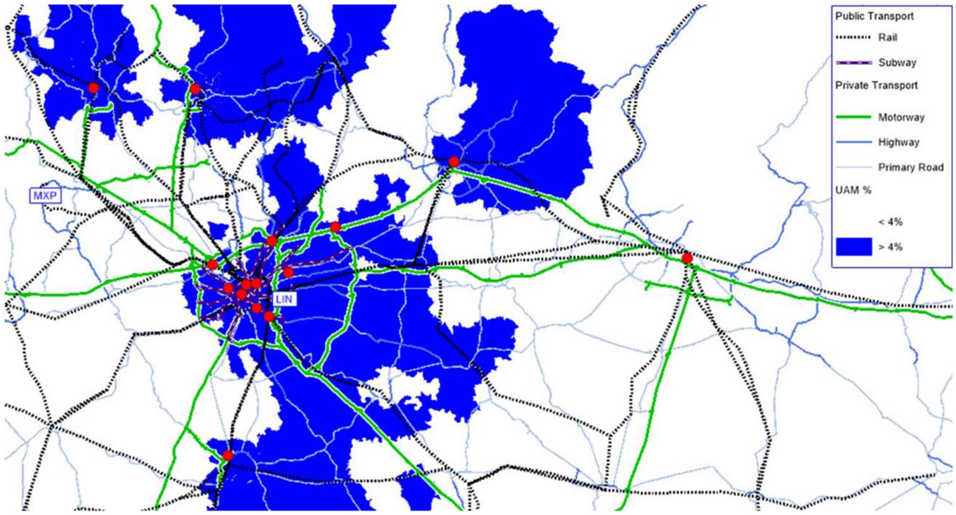

Fig. 9 UAM choice probability for UAM airport shuttles to/from Malpensa (MXP) airport

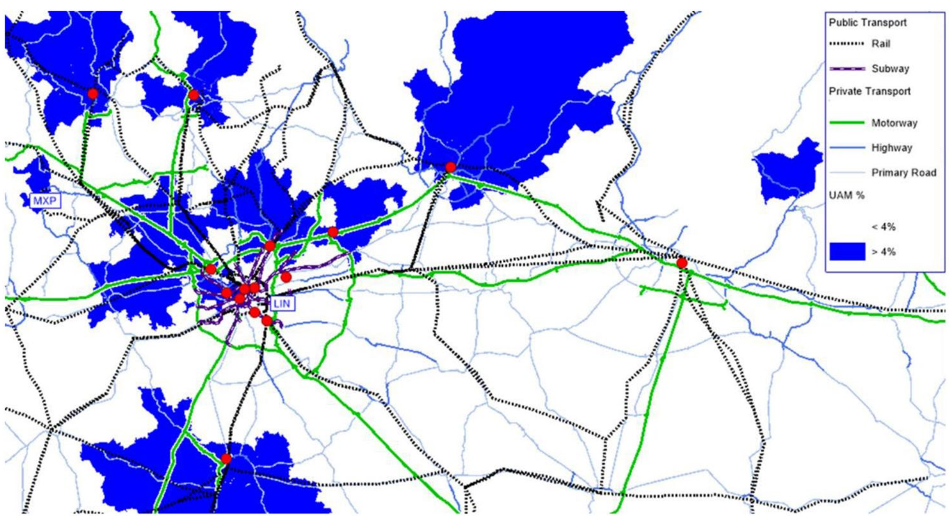

Fig. 10 UAM choice probability for UAM airport shuttles to/from Linate (LIN) airport

resulting in both higher passenger flows and overall modal share. These findings confirm what has been found in [22, 36], i.e. UAM services for airport access and egress could represent the most significant UAM commercial development area.

Comparison with the literature reveals that the average modal shares for UAM intercity connections and air-taxis in the present study (lower than 0.2%) are aligned with those in [28, 30], whereas the modal share estimates for UAM airport shuttles (ranging from 0.6 to 2.1% in the simulated scenarios) are lower than those in [24, 25, 30], but higher than those in [6] on average. It is woth nothing that this comparative analysis ougth to be contextualized within the specific case study, the transportation system in which UAM is integrated, and, most importantly, the assumptions related to UAM fares and service network extension (i.e., number of veritports and routes served). In fact, these assumptions can vary significantly from one study to another, given the ongoing uncertainty about the features of this new mode of transport, which makes a fully comprehensive comparative analysis very difficult.

Among the assumptions of this study it is worth highlighting that the UAM fare structure based on distance is similar to those assumed in [24, 27, 29–31]. In terms of magnitude, the unit kilometer rate assumed, between 3.5 €/km and 3.0 €/km, is aligned with the rate range examined in [30] but are higher than those in [6, 24–28, 31]. This depends on the fact that our scenarios should be interpreted as related to the initial phase of UAM operations. It is plausible to envision that UAM fares could decrease in the long term.

With respect to the number of vertiports in operation, these range from two to seventeen in the simulated scenarios: this is similar to assumptions made in [5, 29–31],

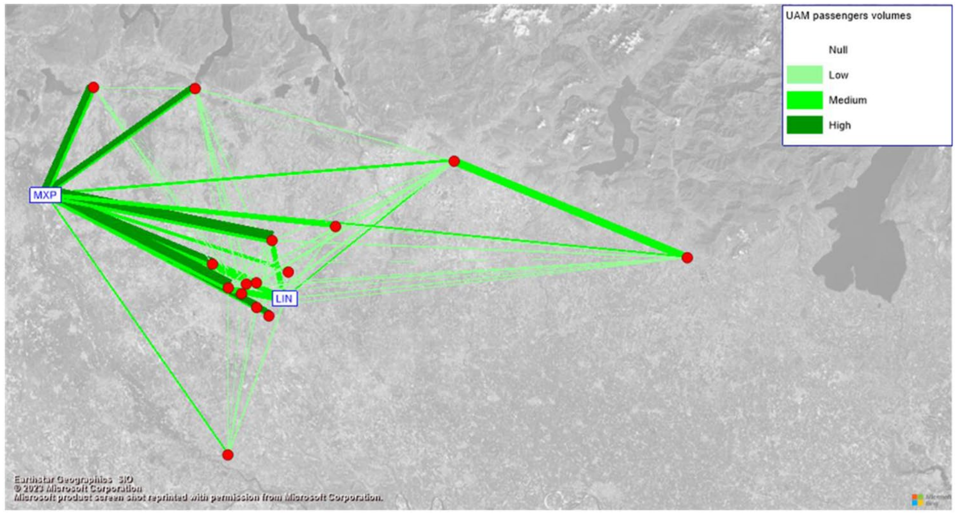

Fig. 11 Vertiport-to-vertiport UAM passengers flows

where only a few vertiports for UAM operations have been introduced, but it is significantly lower than in other studies (see for instance [6, 24–27]). As the UAM service network expands (i.e., the number of vertiports increases), an increase in UAM modal shares is observed. However, their incremental growth is not constant and diminishes progressively as the number of vertiports increases (see the comparison between UAM modal share results from Scenario 1 to Scenario 4 in Table 9).

The relationship between UAM choice probabilities and intercity air service OD distances exhibits a clear inverse proportionality. In other words, the greater the OD distance, the lower the UAM choice probability. This dependency arises from the tradeoff between travel times and costs when competing with other modes of transport, such as private cars, taxis, and public transportation. On one hand, the fact that UAM travel costs increase with distance more than other modes (i.e., the marginal cost per kilometer for UAM is higher than for other modes) tends to reduce the utility of UAM as the distance increases, thereby lowering the UAM choice probability. On the other hand, UAM offers time savings compared to other modes as distance increases (i.e., UAM travel speed is higher than other modes), which tends to increase the UAM choice probability. This relationship is closely tied to the assumed UAM fares. It would be of interest to determine the UAM marginal cost per kilometer that would balance the travel time savings when compared to other modes. However, this could be a topic for future research. Moreover, Fig. 5 shows that UAM choice probabilities are notably high, averaging above 4%, for short service distances ranging from 30 km to 50 km: this convenience range for UAM services aligns with the estimates provided in [40].

6 Conclusions

This paper aims at giving a contribution to the undergoing debate on UAM service attractiveness and on factors affecting the potential demand. Based on random utility mode choice models estimated for the case study of Milan metropolitan area, UAM passengers' flows have been estimated in several scenarios for the following types of UAM services: aerial airport shuttle, intercity air connections, and air-taxi services.

Results show that airport shuttles have a modal share of trips to/from airports (for both business and leisure) in a range of 2-5%. They are more attractive than air-taxis having a modal share in a range of 1-3%. Moreover, the probability of choosing UAM services for intercity travels decreases with the distance and access/egress times to/from the vertiports. Similarly, an inverse proportionality (tough more dispersed) of UAM choice probablities with OD distances has been highlighted for UAM airport shuttle services, but no trends can be observed for UAM air taxis due to high anisotropy of level of service attributes related to the competing modal alternatives in the Milan metropolitan area. Finally, a spatial analysis has proved that vertiport catchment areas expand as competition between UAM services and other transport modes decreases.

Among the limitations of this research, it is worth noting that the UAM travel demand forecasting relies on mode choice models estimated from data obtained through on-site surveys. Although users were introduced to the UAM technology through a video presented during the questionnaire, the inherent nature of the survey methodology means that the immersive experience of the respondents with this new technology migh be not so deep. Consequently, their choices regarding the intention to use it may be biased. Another limitation is related to the mode choice models implemented for simulation. It is important to note that the mode choice models applied were estimated based on a dataset covering UAM level of service attributes for a maximum flight range of 75 km. When these models are applied to longer flight distances than 75 km, we should be aware that the elasticity to time and cost may vary, which could affect the accuracy of travel demand forecasting.

Another limitation is related to the results interpretation. Given that both the estimated UAM choice probabilities (see Figs. 5, 6 and 7) and the estimated UAM modal shares (see Table 9) are relatively small in absolute terms, the results should be interpreted carefully. They should primarily provide general insights (e.g., that UAM services will target a niche market and that UAM airport shuttle services might be more attractive) rather than precise indications on the number of potential UAM users travelling on specific routes.

Future research could investigate the UAM mode choice process in a virtual reality environment (e.g., through the use of headsets) to promote a more immersive experience for respondents. Moreover, the analysis of factors affecting UAM mode choice could be deepened by investigating users' habits of traveling by air or examining how individual traits, such as safety perceptions, influence the probability of choosing UAM services. From the mode choice modeling viewpoint, future studies could use jointly estimated RP and SP models, integrating data from the current RP users' behaviors with hypothetical ones from SP data, thereby mitigating potential biases associated with SP experimental choices.

Regarding assumptions about UAM services, this study considered feedback from industry experts, companies specializing in vertiport and UAM network design, and UAM service operators planning to enter the Italian market. These assumptions could be relaxed in future research. For instance, it would be interesting to analyze different vertiport location settings to evaluate the tradeoff between potential UAM passenger demand, transport accessibility, and spatial equity impacts. Another focus could be on relaxing the assumption of constant per-kilometer UAM fares and simulating the impact on passenger travel demand of dynamic fares based on the UAM dedicated airspace congestion.

Acknowledgements
The authors would like to acknowledge Eng. Luca Barbierato and Eng. Davide Floridi for having contributed to the data analysis and modeling carried out in the present study.

Author Contributions
Pierluigi Coppola: Conceptualization, Validation, Writing-original draft, Writing–review and editing. Francesco De Fabiis:Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing-original draft, Writing–review and editing. Fulvio Silvestri: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing-original draft.

Funding
Not applicable.

Data availability
Research data supporting the findings of this study are not shared.

Declarations

Competing interests
None.

Received: 31 October 2023 / Accepted: 8 December 2024
Published online: 13 January 2025

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