Transport Policy 141 (2023) 129–139

Contents lists available at ScienceDirect

Transport Policy

journal homepage: www.elsevier.com/locate/tranpol

SP surveys to estimate Airport Shuttle demand in an Urban Air Mobility context

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ARTICLE INFO

Keywords:
Airport shuttle
SP techniques
Urban air mobility
Discrete choice models

ABSTRACT

Electric vertical take-off and landing vehicles (eVTOL) are expected to be the key drivers for Urban Air Mobility (UAM) scenarios, by satisfying on-demand air travel needs in the short or mid-term. Despite the high number of eVTOL prototypes, nowadays only few studies have focused on UAM travel demand estimation, in particular Airport Shuttle demand estimation. The aim of this work is to use Stated Preference methods to collect data necessary to understand the main features of the potential UAM Airport Shuttle trip demand, also by calibrating some discrete choice models. Data were collected by both on-line surveys and face-to-face interviews, which captured mainly the Italian context. Three different Multinominal Logit models and a Mixed Logit model have been calibrated in order to identify the main variables driving people's choices for Airport Shuttle services. The results show the positive impact of income, air travel frequency and shared ride in increasing the willingness to use Airport Shuttle services. On the other hand, user that still prefers the ground transportation modes to reach the airport, high ratio between the number of cars and the driving licenses per family unit and the lack of experience with autonomous systems (i.e., driving assistance systems) seem to have a negative impact on people intention to use Airport Shuttle services.

1. Introduction and background

Urban Air Mobility (UAM), also known as Advanced Air Mobility (AAM), promises to realize aerial, fast and dynamic connections between cities and among different city areas in order to transfer people and goods. The introduction of UAM services in several fields – from good delivery to medical aid (Park et al., 2018; Ackerman and Koziol, 2019; Cohen et al., 2021; Claesson et al., 2016) – is encouraged by recent technological developments, such as Unmanned Aerial Vehicles (UAVs) and electrical Vertical Take-Off and Landing vehicles (eVTOLs) among the others. Some initial studies pushing towards the adoption of UAM solutions highlighted the potential of this new urban mode for reducing some of the well-known impacts due to ground traffic flows, such as congestion (Holden and Goel, 2016). However, more recent studies have found that time savings might not be relevant and, in some cases, it is negligible (Postorino and Sarnè, 2020; Pukhova et al., 2021). In addition, more investigation is required for considering UAM as a really disruptive transport solution (Al Haddad et al., 2020). It is expected that UAM passenger services will be realized by eVTOLs, which are considered to be cheaper and less noisy than modern helicopters (Porsche Consulting, 2018). However, several factors have to be examined to realize a successful development of UAM services. As highlighted by the European study on people's concerns towards these systems (EASA, 2021), safety and security are the main worrying factors for UAM services, as well as environmental pollution and noise together with privacy violation. In addition, the EASA study shows that people consider UAM medical aid and goods delivery applications more useful than passenger transportation. On the other hand, there are several opportunities for implementing UAM passenger services such as Air Taxi, Air Ambulance, Intercity flight and Airport Shuttle (AS) services (Goyal et al., 2018). Among these, AS services seem to be the ones with the higher number of advantages (Desai et al., 2021) and the first ones that would be implemented, which is also the result of the EASA study cited above, reporting that people consider AS services as the most useful passenger services. Due to UAV applications in different domains and the potential usefulness of UAM services, many countries around the world have planned to develop UAM services in the next years. In particular, the European Union is actively participating in the research

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https://doi.org/10.1016/j.tranpol.2023.07.019
Received 31 October 2022; Received in revised form 19 July 2023; Accepted 20 July 2023
Available online 21 July 2023

and development of AAM systems in many fields – from medical aid to passenger transportation (Agouridas et al., 2021). In the Italian context some important airports – such as Rome, Venice, and Bologna – declared their interest in developing AS services in the near future. In this perspective, the Italian National Authority for Civil Aviation (ENAC) published a road map for the implementation of AAM services, particularly the first passenger services would be aerial connections between city centres and airports (2025 jubilee in Rome and 2026 winter Olympic Games, ENAC, 2022). This confidence in both UAM opportunities and operational implementation of aerial services is mainly encouraged by the high number of vehicle prototypes (Garrow et al., 2021), which have different range, speed and seat capacity. However, currently there are no defined flight regulations and lower space aerial corridors (Bauranov and Rakas, 2021; Ditta and Postorino, 2021) that would allow urban aerial routes; in addition, only a limited number of studies focus on ground infrastructures, named vertiports (Garrow et al., 2021), which are thought as interchange air-ground nodes for making the aerial service available to passengers.

Although there is a lot of research to be done on these topics, many researchers think that this new concept of aerial services will be adopted in a few years. The success of such implementation, however, will depend on how much travellers would accept this new travel service. In the best of these authors' knowledge, there is a limited number of studies that aim to analyse the driving factors of the potential demand for UAM systems and, in particular, for AS services. For innovative transportation opportunities such as UAM services, it is important to understand people's expectations and especially their travel behaviours. The effective realization of passenger transport services is closely dependent on the suitable estimation of the future demand levels that can be attracted by new transportation modes. At the same time, understanding the potential of UAM services for attracting travel demand can be useful to evaluate the expected impacts that such services would produce on current ground transportation systems.

In the above perspective, this paper focuses on the analysis of passengers' willingness to use AS services by exploiting data collected by online surveys distributed in the EU area, with additional face-to-face data also gathered at Bologna Airport (Northern Italy), which is an important large regional airport with many national and international air links. Starting from the information obtained by suitably planned Stated Preferences (SP) surveys, some mode choice models have been calibrated in order to analyse the main key factors underlying travel demand for AS services. Three different Multinominal Logit (MNL) models have been calibrated and analysed to understand the influence of the different variables from the users' point of view, while a Mixed-Logit (ML) model has also been used to test sample heterogeneity. The simple MNL model has been chosen, among the others, to provide some preliminary information about user's preferences, so that more detailed models could be implemented later.

The paper is organized as follows. Section 2 contains an overview on previous works on UAM demand estimation. Sections 3 explains the methodology used to design the survey. The results obtained by the survey are analysed in Section 4 while in Section 5 four models, calibrated by using the collected SP data, are discussed. In Section 6 a comparison of the results obtained by the different models is carried out together with the policy implications and the main study limitations. Finally, Section 7 summarizes the main findings and conclusions.

2. UAM demand estimation

In recent years, transportation service providers – such as Uber – have been engaged in developing Air Taxi services (Holden and Goel, 2016) attracted by the idea of "flying cars" and possible operational scenarios (Cohen et al., 2021; Postorino and Sarnè, 2020). However, Air Taxis services could be difficult to implement (Desai et al., 2021) while AS services seem promising even in the short/mid-term. In fact, AS services are intended to connect airports with surrounding regions and points of interest in metropolitan areas (Shaheen et al., 2018), thus ensuring a fast connection between the airport and its catchment area. Moreover, air transportation demand, especially at regional airports, could increase due to the use of shared AS services (Roy et al., 2019).

In this perspective, several cities such as London, Munich, and Singapore (Cohen et al., 2021; Volocopter, 2022) have shown interest to test and develop UAM services. As an example, for the 2024 Olympic games, the city of Paris aims to launch an AS service which will connect Charles de Gaulle airport with the city centre.[1] Similarly, thanks to a partnership with a European eVTOL manufacture, cities such as Rome, Venice, and Bologna in Italy, would like to develop AS services in the short/mid-term.[2]

A critical aspect about the implementation of AS services – and UAM systems in general – is the estimate of the travel demand level for them. Although the EASA report, cited above, focused on UAM system acceptance and expectations, however, it did not examine the potential passenger demand for AS services. Knowledge about the expected demand levels is important for the system design and to assess its performances, particularly they might have great importance for several stakeholders. For example, the (additional) demand level that can be gathered by AS services could expand the airport catchment area, which is one of the major interests of airport operators. Moreover, high demand levels could bring advantages to eVTOL manufactures and ground transport operators. In fact, the former could increase the market for their aircraft, whereas the latter could provide services to access or egress the vertiports (i.e., eVTOL stations acting also as passenger terminals for aerial services) in order to rise their revenues.

At a first attempt, simulation techniques have been used to understand the relationships between UAM demand levels and relevant variables. Particularly, some scenarios have been identified and simulated by using suitable software and variations of demand levels have been computed when some relevant elements change. For example, an increase in the number of vertiports seem to positively affect the number of passengers (Rimjha et al., 2021; Wu and Zhang, 2021), although the positive marginal effects become negligible as the number of vertiports exceed a given threshold. The influence of variables such as access/egress time to/from the vertiport, processing time at the vertiport, boarding time and trip monetary costs were also tested. The results obtained by the different simulations show that an increase of access, processing or boarding time causes, as expected, a significant decrease of demand levels (Balac et al., 2019; Pukhova et al., 2021; Rimjha et al., 2021; Wu and Zhang, 2021).

Some other studies in the literature aim to estimate UAM demand levels by using socio-economic variables at a significant aggregated level, which could greatly influence the results. An estimate of the expected 2042 UAM demand level for several metropolitan areas has been obtained by a gravity model with socio-economic explanatory variables such as Gross Domestic Product (GDP), population and ticket price (Becker et al., 2018). Further studies provided similar aggregated analyses for estimating the demand levels for AS services in different US cities such as Los Angeles, Atlanta and New York (Roy et al., 2020). Socio-economic variables have been also used by Goyal et al. (2021) – with several constraints such as willingness to pay, infrastructure capacity and noise restrictions – to simulate many UAM scenarios and estimate the corresponding demand levels. The results show that large population cities with limited urban areas (i.e., high-density areas), high GDP per capita and high air passenger demand are good candidates for adopting UAM services (Becker et al., 2018). On the other hand, the factors that negatively affect UAM demand levels are monetary costs,

[1] https://presse.groupeadp.fr/pontoiseairfield-uamtests/?lang=en (Accessed: June 2022).

[2] https://www.atlantia.com/en/w/-urban-blue-a-company-for-the-international-development-of-urban-air-mobility-uam-launched-today (Accessed: June 2022).

aircraft designed range and cruise speed (Roy et al., 2020; Mayakonda et al., 2020).

More detailed information on potential travel demand for UAM services and users' characteristics may be obtained by SP surveys. SP methods are useful to collect data for hypothetical alternatives and scenarios that have not been implemented yet. In addition to statistical analyses and figures, collected SP data can be used to calibrate discrete choice models to assess potential demand levels, as suggested by some reference books (see for example Cascetta, 2001). Moreover, SP surveys may help identifying users' satisfaction towards the used transportation mode (Susilo and Cats, 2014) and the effects of some relevant variables (such as educational level or social environment) on people's choices (Groth et al., 2021; Jia and Chen, 2021). By adopting this method, important variables from the users' perspective can be identified (Krauss et al., 2022; Carrone et al., 2020; Rotaris et al., 2021). For example, in recent years SP surveys have been widely used to evaluate user's perception and demand levels for Automated Vehicles (AVs) (Becker and Axhausen, 2017). Due to some similarities between UAM and AV scenarios, SP analyses for Air Taxi services (Fu et al., 2019) may use the results obtained in AV studies as a baseline (Gkartzonikas and Gkritza, 2019; Becker and Axhausen, 2017). Furthermore, SP analyses of UAM scenarios showed that variables such as trip safety, affinity to automation, ethical and data concerns could have an impact on the expected demand levels (Al Haddad et al., 2020). Moreover, some gender differences were highlighted by the results obtained in the Ingolstadt area (Southern Germany). In particular female respondents seem less interested in UAM services than their counterpart (Janotta et al., 2021) and have more concerns especially about safety and security. However, this result is not confirmed by other SP surveys (Fu et al., 2019; Keller et al., 2022).

As for connections, long distance ones are considered the most suitable for UAM services (Shaheen et al., 2018; Keller et al., 2022). In this perspective, Garrow et al. (2019) conducted an investigation in which only people travelling at least 30 min and with an annual income higher than a defined limit ($75000) were interviewed and a mode choice model was calibrated, founding that the variables with the strongest impact on Air Taxi demand are access/egress times and eVTOL operation costs, further confirmed by other studies (Haan et al., 2021). However, although the study by Garrow et al. (2019) was intended to address supposed captive customers for UAM services, targeting upper income residents limits the results of the study and could lead to biased market estimates. Another SP research conducted in Czech Republic shows that when ground transportation mode satisfaction is low, respondent's willingness to use UAM increases and vice versa. Finally, SP surveys allowed highlighting respondents' worries about AAM services in terms of privacy, safety noise and environmental pollution, which have been described by different studies (EASA, 2021; Al Haddad et al., 2020).

From the above overview, it emerges that most of the studies in the literature focuses on Air Taxis demand estimation and only a limited number aims to investigate the demand levels for AS services, although stakeholders and policy makers agree that AS services would be the first to be implemented. In this perspective, this paper focuses on the analyses of factors that would affect the possible future demand level for AS services by using data obtained by both RP and SP surveys.

3. Methodology: assumptions and survey design

This study wants to explore user's attitudes towards the introduction of fast aerial connections between airport terminals and one or more metropolitan areas, as an alternative to, or an integration of, the current ground transportation system.

In order to assess users' willingness for AS services, a survey has been designed and the questionnaire, implemented on Google Forms, has been distributed on several platforms (LinkedIn, academic websites and other social media). Particularly, the respondents have been contacted by using the social networks associated to the above platforms, which captured mainly Italian people. Both RP and SP data have been collected from April to June 2022. In addition, face-to-face interviews have been conducted in several terminal areas of Bologna Airport (Northern Italy) – i.e., lounge business, check-in and boarding gate areas. The survey was completely anonymous, complying with the EU General Data Protection Regulation (GDPR)[3] and it has been proposed to individuals with more than 18 years, without any social or gender discrimination.

By using RP and SP "data fusion" techniques (Mark and Swait, 2004), current users' behaviour (RP data) and future users' plans (SP data) can be analysed. Particularly, the demand features of not-existing transportation systems cannot be obtained by using only RP data but can be achieved by using also SP data (Kroes and Sheldon, 1988). Therefore, the questionnaire includes two main sections, Revealed and Stated Preference sections. It is worthwhile to note that SP methods are largely used for testing alternatives and/or scenarios not existing yet by designing the choice context – such as UAM services – rather than recording choices in a given context – as in the case of RP surveys. On the other hand, some limitations of using SP data are the introduction of some distortions in the results (and in the calibrated models) due to the possible differences between stated and actual choice behaviour, which depend on both the SP survey technique in itself and the way the surveys is designed. While the first error cause cannot be removed, the second one can be avoided by designing and executing carefully the surveys. To limit the above distortions, which in this case are due to user's lack of experience with UAM services, scenarios have been designed as simple as possible, the description of both the vehicle and the context has been provided and the number of factors and SP alternatives is as smaller as possible (Cascetta, 2001).

The Revealed Preference section includes three different classes of questions (Table 1). First, nine questions address socio-economic features and two questions explore user's experiences about sharing mobility and driving assistance systems. In order to acquire reliable statistics, the average income has been inferred mainly from information on current employment, as respondents are often reluctant to provide a true indication of their income. Similarly, car availability has been deduced from the number of driving licences per family unit.

The second class includes six questions, which focus on both air travel habits and characteristics of the last air trip. Finally, the third class collects data about the last chosen ground transportation mode for reaching the origin airport. This class contains three to five questions – depending on the used transportation mode – about travel time (such as time spent to access the bus stop/train station, time on board) and monetary costs (such as airport parking area costs, motorway fees, fuel consumption, bus/train/taxi fares) that characterize the transportation mode used to reach the airport. In addition, for each ground transportation mode respondents are asked to provide a satisfaction rate, from 1 to 5 (totally unsatisfied and totally satisfied respectively). Moreover, further specific questions have been asked for private car users, such as being the driver or a passenger.

The Stated Preference survey section starts with a brief description of the Airport Shuttle service characteristics by focusing on the features of the flying vehicle and on some key factors of the proposed service. Other information is provided such as the allowance to use smartphone or laptop on board, the number of boarding luggage and the presence of a pilot (manned service). To collect suitable SP data, the respondents are addressed to different fact sheets depending on the declared distance range travelled to reach the airport. Several related studies (Bacchini and Cestino, 2019; Hagag et al., 2021) and eVTOL technical information provided by manufactures[4] were used to identify three distance ranges – 30, 60, 90 km – which are likely to be included in the airport catchment

[3] Official Journal of the European Union, 4.5.2016, L 119/1.

[4] https://www.volocopter.com/wp-content/uploads/20220607_VoloCity_Specs.pdf (Accessed June 2022).

Table 1
Revealed Preference items.

	First Category: *Socio-Economic Information*	Second Category: *Air Travel and Airport Access Information*	Third Category: *Last transportation mode used to reach the airport and its characteristics*
Data Obtained	• Age • Gender • Educational level • Occupation • Number of cars owned • Experience of sharing mobility and driving assistance	• Air travel frequency • Air travel reason • Last air travel data (trip origin, origin airport)	• Car • Taxi • Public Transport (Train, Bus) • Car - Sharing

area (Rothfeld et al., 2019). Furthermore, some fixed value variables are considered, i.e., the vertiport access time, the waiting time and the AS monetary cost per km (Table 2). This latter has been used to compute the service fare based on the declared travelled distance. Only the due fare has been proposed to respondents.

The aforementioned values have been assumed in the perspective of a mid-term scenario (2030–2035), in the hypothesis that at that time there will be a suitable distribution of vertiports in the study area, easily accessible by ground transportation. The egress time from the vertiport has not been considered because the destination vertiport has been considered placed next to the airport or embodied in the airport.[5] As reported in Section 2, access and egress time seem to affect significantly the total travel time (Balac et al., 2019; Lim and Hwang, 2019). However, in this SP experiment, which considers trips towards the airport, the assumption that the vertiport egress time at destination is negligible is coherent with recent orientations encouraging to start with AS services, in which the vertiport for accessing/egressing the air passenger terminal is included in the airport area, thus ensuring fast air-ground connections. As for vertiport waiting time – which consists of operational times such as security and boarding – it has been assumed by considering some UAM simulation results in the literature (Rothfeld et al., 2021) in order to ensure an optimal level of service based on airport standards (IATA, 2019). Finally, the AS monetary cost per km has been defined based on several studies (Al Haddad et al., 2020; Fu et al., 2019; Pukhova et al., 2021). It is worthwhile to note that the assumed monetary cost per km – which is equal for all the distance ranges – was derived from the literature by considering a mid-term scenario. Although it might be considered under-estimated for unshared services, however high-automation levels – such in AS services – would confirm this preliminary cost estimate. In any case, cost reference values are still rather arbitrary, as the final cost will depend on several variables – which in turn need to be defined and estimated – and the operating environment as well as the business model adopted. SP methods offer the advantage to set cost values that will be considered by users as part of the alternative, thus reducing potential biases. Finally, it has been clearly described to respondents that the proposed AS service has the same safety standards as traditional aviation.

The SP alternatives come from the combinations of two varying factors (running time and monetary cost). For each factor, two different levels were considered with regard to eVTOL prototype features (Garrow et al., 2021). Particularly, the estimated cruise speed (120 km/h or 200 km/h) has allowed identifying two sets of running times for the three different range distances. Similarly, seat capacity values (1 or 3 passengers per aircraft) have been used to compute appropriate fares related to unshared rides or rides shared with two other passengers, the latter being less expensive. The "full factorial design" obtained by combining levels and factors is showed in Table 2 for each considered travel range.

Each respondent is assigned to the correspondent SP scenario (30, 60 or 90 km), depending on the distance travelled to reach the airport in his/her last air trip. Afterwards, the respondent has been asked to rank the available travel alternatives, i.e. the transportation mode used to reach the airport and the four SP alternatives. As an example, the SP scenario for 30 km distance range is shown in Fig. 1.

To identify users' declared preferences, respondents had to rate some variables based on the importance (from 1 to 5) they give to each variable (i.e., total travel time, waiting/service time, access/egress time, cost and privacy). Lastly, to investigate respondent's perception about unmanned aerial vehicles, they had to indicate if they would use an AS service operating with autonomous aerial vehicles, i.e. without pilot on board.

4. Data analyses

The number of collected responses was 225, which reduced to 197 because some invalid or biased observations were excluded.[6] Regarding the information obtained by the RP survey, the sample is mainly composed by EU citizen with a little gender difference in the sample (only a little bit more male than female respondents). Furthermore, the majority of the respondents are in the age range 18–45 years, employees or students with, in general, a high education level. Occupations such as self-employed and manager positions are mainly declared by older respondents. Moreover, the most common air travel reason was "leisure" followed by "work" and "study". However, the percentage of people that were travelling for work purposes is not negligible. Finally, it is important to note that the over-representation of some respondents' categories in the sample (e.g., young respondents) could be caused by the on-line distribution method used to share the survey (social media or academic websites). To expand the amount of data and includes groups not "captured" by the on-line questionnaire, some face-to-face interviews were conducted at Bologna airport, which also reduces potential biases as on-line respondents might be categorised as "technology savvy". Table 3 summarizes the main sample features for all the collected data (online and face-to-face surveys), which refer to the population of the social networks of the considered platforms, and the average number of passengers for the average traffic day at Bologna airport.

As expected, the most chosen transportation mode used to reach the airport is the private car. In details, 60.8% of the respondents used the private car to reach the airport and, in particular, 43.2% used the private car as passenger and 17.6% as driver. Public transport (PT), taxi and train have been used by a limited number of travellers (16.6%, 11.6% and 11.1% respectively). Despite their low utilization rate, these two latter transportation modes scored the highest respondent satisfaction

[5] This assumption is based on current trends and tests that have been planned and made in some cities, e.g. Rome, Italy, October 6, 2022 (see also at: https://www.volocopter.com/newsroom/italys-first-vertiport-deployed-at-fiumicino-airport/), Paris, France, November 10, 2022 (see also at: https://skyports.net/vertiport-testbed-for-european-urban-air-mobility-testing-inaugurated-in-paris/).

[6] Although the number of responses could seem limited, a check has been conducted by using a plus or minus 10 per cent margin of error (ME) to verify the suitability of the sample, which has confirmed its appropriateness (see for example Deziel, 2018).

Table 2
Full factorial design for 30, 60 and 90 km distance ranges.

SP Alternatives	30 km Scenario		60 km Scenario		90 km Scenario	
	Factors		Factors		Factors	
	Monetary Cost (€)	Running Time (min)	Monetary Cost (€)	Running Time (min)	Monetary Cost (€)	Running Time (min)
1	*60*	*15*	*120*	*30*	*180*	*45*
2	*60*	*9*	*120*	*18*	*180*	*27*
3	*20*	*15*	*40*	*30*	*60*	*45*
4	*20*	*9*	*40*	*18*	*60*	*27*

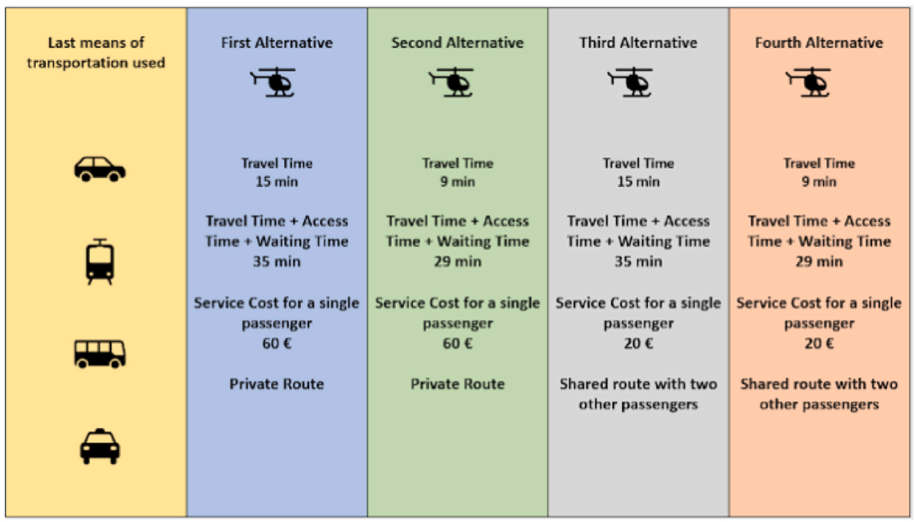

Fig. 1. Example of Stated Preference scenario for the 30 km distance range.

Table 3
Sample composition.

CHARACTERISTICS		PERCENTAGE
NATIONALITY	Italian	90.4%
	Other	9.6%
AGE	18–25	33.2%
	26–35	38.7%
	36–45	13.1%
	46–55	10.1%
	56–65	4.5%
	>65	0.5%
GENDER	Female	40.2%
	Male	58.8%
	Prefer not to answer	1%
OCCUPATION	Unemployed	0.5%
	Student	29.6%
	Employee	51.8%
	Self-employed	11.1%
	Manager	7%
EDUCATION	High school or lower	26.1%
	Bachelor's or Master's Degree	55.8%
	PhD or specialization course	18.1%
TRAVEL REASON	Work	19.1%
	Study	7.5%
	Leisure	73.4%
FREQUENCY	Annually	44.2%
	Biannually	19.1%
	Three-Monthly	18.6%
	Monthly	15.6%
	Weekly	2.5%

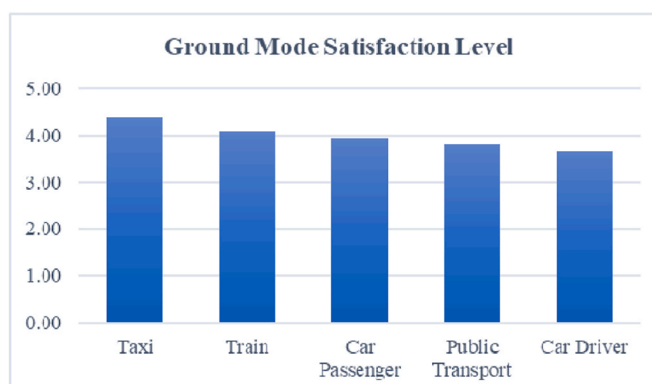

Fig. 2. Satisfaction of the different ground transportation alternatives to access the origin airport.

levels as summarized in Fig. 2, where satisfaction levels range from 1 (Totally Unsatisfied) to 5 (Totally Satisfied). On the contrary, it emerged that car drivers were less satisfied and even public transport scored a higher satisfaction value. The difference in the satisfaction level between car drives and car passengers seems to affect users' choice in the SP survey part. In fact, car drivers – who are the least satisfied – declared a higher willingness to use AS services compared to car passengers (Fig. 3). This difference can be due to factors such as the lower perception of monetary costs and less stress associated with driving activities of car passengers compared to car drivers.

Starting from the choices declared by the respondents in the SP module, several factors can be identified that support the introduction of AS services (Table 4). Firstly, the intention to use AS services seems to be mainly influenced by occupation, travel purpose and air travel frequency. Respondents who declared to work as manager or self-employed show higher willingness to use AS services compared to students and employees. Moreover, people who travel for business and study reasons would be more interested in fast connections between airports and

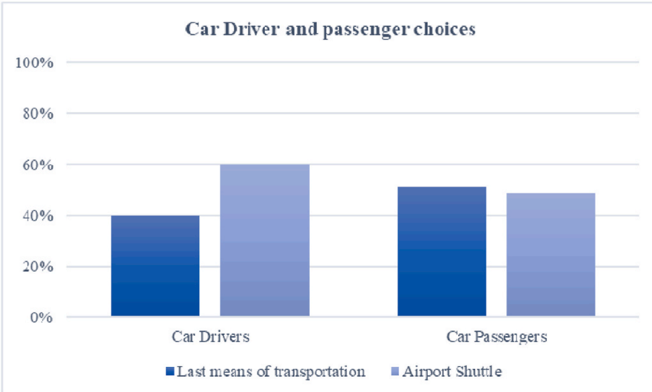

Fig. 3. AS choices by car drivers and car passengers for accessing the origin airport.

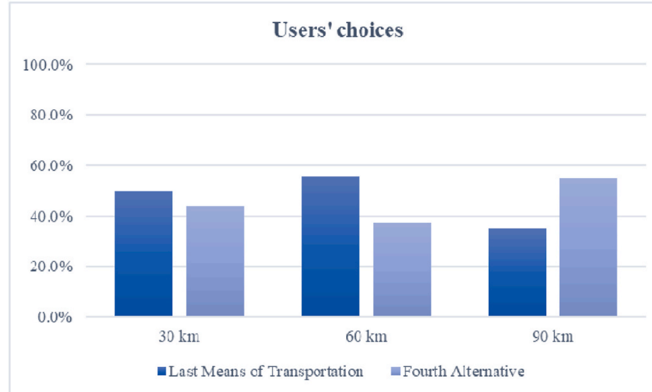

Fig. 4. Respondents' preferences for 30, 60 and 90 km.

Table 4
Preferences for AS services and respondents' features.

Characteristics		% of respondents confirming their used mode	% of respondents choosing AS services
Age	18–25	43.9%	56.1%
	26–35	53.2%	46.8%
	36–45	46.2%	53.8%
	46–55	40%	60%
	>56	60%	40%
Gender	Female	46.3%	53.8%
	Male	49.6%	50.4%
Occupation	Student	52.5%	47.5%
	Employee	47.6%	52.4%
	Self-employed	45.5%	54.5%
	Manager	42.9%	57.1%
Education	High school or lower	44.22%	55.8%
	Bachelor's or Master's Degree	54.1%	45.9%
	PhD or specialization course	36.1%	63.9%
Travel Purpose	Work	42.1%	57.9%
	Study	40%	60%
	Free Time	50%	49.3%
Frequency	Annually	50%	50%
	Biannually	63.2%	36.8%
	Three-Monthly	32.4%	67.6%
	Monthly	45.2%	54.8%
	Weekly	40%	60%

urban areas made by eVTOLs compared to people who travel for leisure. Furthermore, a significant average difference in the intention to use AS services can be seen between people who travel frequently by plane (three-monthly or more) and the ones who travel annually. Another important factor, which seems to be relevant in addressing users' preferences, is the education level. People who got a PhD or a specialization course show a significantly higher intention to use AS services compared to people with a lower education level. Furthermore, an important variable that could influence users' choices is the travel distance to reach the airport. User's preferences to use AS services increase as the travel distance to reach the airport increases. In fact, as reported in Fig. 4 the percentage of users confirming their last used ground transportation mode to reach the airport, against the AS fourth alternative (the most convenient one), drops in the 90 km scenario, which seems the most suitable distance range for starting conveniently AS services. On the other hand, for the 30 and 60 km scenarios, most of the respondents seem to prefer their last used ground transportation mode. However, in these two latter scenarios the AS fourth alternative has been chosen, on average, by 40% of the respondents, which suggests that AS services could be competitive with ground transportation modes even for short distances (30–60 km).

Finally, some respondent's characteristics seems to have only a limited influence on the willingness to use AS services. For instance, gender does not seem to affect significantly people choices, while only a slight difference has been detected for younger respondents (18–45 years) against older ones (higher than 45 years), the former seeming to be more inclined to use AS services on average.

5. Model calibration

Data collected by both RP and SP surveys have been used to calibrate some discrete choice Multinominal Logit (MNL) models and a Mixed Logit model, run by the free software Biogeme (Bierlaire, 2020). The choice set is composed of three SP alternatives – AS 2, AS 3 and AS 4 (see also Section 3) – and the chosen RP transportation mode, i.e., Private Car (PC), taxi, train and Public Transport (PT). No respondents have chosen Alternative 1, which in fact is the worst one and acted as "control alternative" for detecting potential biases.

At a first stage, three different MNL model specifications have been tested in order to better identify the importance of the different variables and to better understand the factors that drive UAM demand.

The first MNL model, which can be considered as the reference case, includes six relevant variables, i.e. monetary cost (MC), total travel time (TTT), privacy (P), age (Age), frequent flyer (FF) and "RP mode choice" (RP-C) dummy variable, which takes value 0 if the respondent chooses one of the AS alternatives and value 1 if the respondent confirms the initially chosen RP mode (Table 5). Total travel time has been measured in hours and the monetary cost has been measured in €/100. Privacy takes value 1 for all the alternatives that allow a private run and 0 otherwise. Age and frequent flyer are still dummy variables (0,1). If the respondent is young (less than 35 years) the age variable takes value 1, while frequent flyer takes value 1 if travel frequency is higher than biannually.

The results of the first model show the importance of monetary costs, whereas the total travel time seems to have a minor impact on the demand. In addition, using a private ride, age factor and being a frequent air traveller seem to positively affect the choice of AS services. On the other hand, as expected, users that confirm their initial RP choice are less likely to use AS services to reach the airport.

The second MNL model (Table 6) has been specified by adding a variable that tries to capture the users' experience regarding automation (e.g., driving assistance services), called "affinity to automation" (AtoA). Affinity to automation is a dummy variable that takes value 1 if the respondent declares no experience with driving assistance systems. The other variables are measured as in Model 1. As for the new introduced variable, its negative sign shows the existence of some scepticism towards advanced autonomous transportation modes by users who have a

Table 5
Estimated coefficients for the MNL - model 1.

Variables	Alternatives						
	PC	Taxi	Train	PT	AS 2	AS 3	AS 4
TTT (h)	−0.69 (−2.07)	−0.69 (−2.07)	−0.69 (−2.07)	−0.69 (−2.07)	−0.69 (−2.07)	−0.69 (−2.07)	−0.69 (−2.07)
MC (€/100)	−2.46 (−4.76)	−2.46 (−4.76)	−2.46 (−4.76)	−2.46 (−4.76)	−2.46 (−4.76)	−2.46 (−4.76)	−2.46 (−4.76)
RP -C	/	/	/	/	−1.02 (−3.7)	−1.02 (−3.7)	−1.02 (−3.7)
Age<35	/	/	1.21 (4.5)	1.21 (4.5)	/	/	1.21 (4.5)
P	0.66 (2.34)	0.66 (2.34)	/	/	0.66 (2.34)	/	/
FF	/	/	/	/	/	/	1.2 (4.16)

* not significant at 5% level (*t*-test in brackets).
Adjusted $\rho^2 = 0.265$.
Value of Time (VOT)=28 €/h.
LL=-194.69.

Table 6
Estimated coefficients for the MNL - model 2.

Variables	*Alternatives*						
	PC	Taxi	Train	PT	AS 2	AS 3	AS 4
TTT (h)	−0.75 (−2.24)	−0. 75 (−2. 24)	−0. 75 (−2. 24)	−0. 75 (−2. 24)	−0. 75 (−2. 24)	−0. 75 (−2. 24)	−0. 75 (−2. 24)
MC (€/100)	−2.33 (−4.47)	−2.33 (−4.47)	−2.33 (−4.47)	−2.33 (−4.47)	−2.33 (−4.47)	−2.33 (−4.47)	−2.33 (−4.47)
RP -C	/	/	/	/	−0.92 (−3.2)	−0.92 (−3.2)	−0.92 (−3.2)
Age < 35 years	/	/	1.19 (4.43)	1.19 (4.43)	/	/	1.19 (4.43)
P	0.60 (2.09)	0.60 (2.09)	/	/	0.60 (2.09)	/	/
FF	/	/	/	/	/	/	1.22 (4.23)
AtoA	/	/	/	/	−0.39* (−1.33)	−0.39* (−1.33)	−0.39* (−1.33)

* not significant at 5% level (*t*-test in brackets).
Adjusted $\rho^2 = 0.265$.
Value of Time (VOT)=32.2 €/h.
LL = -193.81.

low level of experience on driving assistance services. However, the "affinity to automation" variable is not significant at the fixed level (5%), and although the reluctance for autonomous vehicles should be considered because it could affect negatively the use of AS services, nevertheless it seems that in general users give more relevance to level of service factors rather than to autonomous/automated technologies.

Finally, the third MNL model (Table 7) has been specified in order to test the influence of variables such as occupation (shadow variable for the average income), car availability, CA (measured as the ratio between the number of cars and driving licenses per family unit) and travel reason, TR (reference: leisure). Occupation and travel reason are dummy variables, particularly occupation takes value 1 if it is different from "student" or "unemployed", while travel reason takes value 1 if it is equal to leisure. The other variables are measured as in the previous two models. In this specification, privacy and air travel frequency have been neglected as some preliminary tests do not show relevant additional information. From the results it emerges that valuable working positions (and, as a consequence, the annual income) would increase the propensity to use AS services. Same effects have been observed for taxi and train. Taxis have some similarities with AS services, because both are thought for providing fast, private and high-level transportation services. As for train, a high number of respondents travelled by high speed trains (with higher costs and lower travel time compared to regional trains) to reach the airport. Again, there would be a similarity with rather expensive but fast AS services. On the other side, a high ratio between the number of cars and driving licenses per family unit seems to be an obstacle to the use of AS services, but also to the use of all the other alternatives that are different from private cars. Finally, people who travel for leisure seem to have less propensity to use AS services; however, the estimated coefficient is not significant at the fixed level (5%).

Some common results can be deduced from the three MNL models. All the calibrated models confirm the importance of age in the willingness to use shared AS services, the relevance given by users to privacy as well as to ground transportation modes that are already satisfactory for them, which could be a key obstacle to the development of AS services. Finally, the different models have similar adjusted ρ^2 values, but the first

Table 7
Estimated coefficient for the MNL – model 3.

Variables	*Alternatives*						
	PC	Taxi	Train	PT	AS 2	AS 3	AS 4
TTT (h)	−0.81 (−2.36)	−0.81 (−2. 36)	−0.81 (−2. 36)	−0.81 (−2. 36)	−0.81 (−2. 36)	−0.81 (−2. 36)	−0.81 (−2. 36)
MC (€/100)	−1.92 (−2.59)	−1. 92 (−2.59)	−1. 92 (−2.59)	−1. 92 (−2.59)	−1. 92 (−2.59)	−1.92 (−2.59)	−1. 92 (−2.59)
RP -C	/	/	/	/	−0.92 (−3.29)	−0.92 (−3.29)	−0.92 (−3.29)
Age < 35 years	/	/	/	1.14 (5.93)	/	/	1.14 (5.93)
CA	/	−0.69 (−1.98)	−0. 69 (−1.98)	−0. 69 (−1.98)	−0. 69 (−1.98)	−0. 69 (−1.98)	−0. 69 (−1.98)
Occupation	/	0.5 (1.97)	0.5 (1.97)	/	0.5 (1.97)	/	0.5 (1.97)
TR	/	/	/	/	−0.51* (−1.68)	−0.51* (−1.68)	−0.51* (−1.68)

* not significant at 5% level (*t*-test in brackets).
Adjusted $\rho^2 = 0.237$.
Value of Time (VOT)=42.18 €/h.
LL=-201.45.

two have a slightly better value.

To explore the existence of sample heterogeneity, a Mixed Logit (ML) model (Train, 2009; Brownstone et al., 2000; Yannis and Antoniou, 2007; Baek et al., 2021) has also been tested for analysing user's behaviour. Particularly, ML models allow estimating random taste variation and correlation in unobserved factors. The tested ML model has been specified as Model 1 (see Table 5), but travel time and cost coefficients have now been considered to have a lognormal distribution, which is often used for coefficients that are expected to have the same sign for each respondent (Train, 2009), as in the case of time and cost. The lognormal distribution allows theoretical consistency with the expected signs of the coefficients although it could generate likelihood functions rather flat around the maximum, thus making convergence difficult to achieve, and could produce biased mean value or overestimated standard deviations due to its long tail (Hess and Polak, 2004; Sillano and de Dios Ortúzar, 2005).

To obtain a steady estimate of the coefficients, several Monte Carlo simulations of 500 draws have been performed by different starting coefficient values, in order to obtain a convergent, stable solution. The results (Table 8) show that all the variables are significant at the fixed level (5%), except for privacy, which is significant at 10%. The adjusted ρ^2 value is better than the ones in the MNL calibrations, which is a common result in mixed-logit applications because the estimation of ML models results in a substantial improvement of fit over MNL models (Hensher, 2001). Travel time and cost variables seem to play a relevant role in choosing the transportation mode; in addition, their variance parameters are significant, thus showing the existence of sample heterogeneity.

6. Discussion

The first relevant result that emerges from all the calibrated models is the importance of the monetary cost variable (MC), which is highly significant in almost all the models. This result confirms the score assigned by the respondents to the different variables in the specific survey part, as described in Section 3. In fact, the cost of the service is considered the most important variable with an average score of 4.23 (out of 5). In details, 83% of young respondents (18–35 years) assigned a score 4 or 5 (out of 5) to the service cost. Particularly, young users would use AS services if it were possible to share the route – and thus the monetary costs – with other passengers. On the other hand, only a limited number of people seems available to pay more to travel on a private route. In Model 1 and Model 2, the privacy (P) coefficient, which identifies private rides, has a similar value and is significant at the assigned level. In addition, it should be noted that only 24% of respondents who assigned a score 4 or 5 to privacy were younger than 35, thus suggesting that privacy is more important for older people (>35 years) compared to young people (18–35 years). This result suggests that the main target users for AS services should be young travellers sharing a run, at least in the first stage of AS implementation.

The RP mode choice variable (RP-C), which has been introduced in all the considered specifications, is significant in all the calibrated models. As it can be seen, users' preference for the ground mode they usually utilize has a negative effect on the choice of advanced flight alternatives for reaching the airport, which has been already discussed in Section 4. Particularly, for relatively small distances (between 30 and 60 km) from the airport, data have showed that users prefer to travel by their last used ground transportation mode, which is confirmed again by model calibration.

In Model 1 and Model 2 a similar Value of Time (VOT) – respectively 28 €/h and 32 €/h – has been estimated, whereas the VOT obtained in Model 3 is slightly higher (42.18 €/h). The estimated VOTs – which are averaged over the different alternatives considered in the study (from public transport to AS services) and for people with different age, occupation, educational level, and other socio-economic categories – overall are in line with the results obtained in other studies regarding UAM services. Particularly, values are close to the ones that have been obtained for the Munich scenario (Fu et al., 2019), where different VOTs have been estimated separately – from public transport (27.47 €/h) to Air Taxi services (44.68 €/h). It is also worthwhile to note that here the airport access trips are considered, which are perceived more important – and then more valuable – than other trips (i.e., commuting). In fact, reliability, efficiency and fastness of ground transportation modes for reaching the airport are relevant factors for travellers, that do not want to risk losing their flight due to deficiencies in ground access transportation modes (Postorino et al., 2019). Then, it is realistic to consider that users' willingness to pay for saving time – and avoid, for example, flight loss risks – is significantly higher for air travellers than for commuters. As final comment about the VOT values, although there is some difference between the VOT values obtained by Models 1&2 and Models 3, it is too early to say which value would be more realistic, because UAM services are still far from being effectively realized and fully understood by potential users. Finally, as for Model 4 the VOT value has not been computed, based on the criticisms outlined by several authors (see for example Hess and Polak, 2004) about the bias due to the use of the ratio of means approach – generally used for computing VOT values – which is rather high in asymmetrical distributions like the lognormal. It is out of the scope of the paper to explore other approaches for computing the VOT from Model 4.

Another common result in Model 1 and Model 2 is the positive influence of air travel frequency (FF) for the intention to use AS services. Like the privacy coefficient, the frequent flyer coefficient has similar values and significance levels in the two different model specifications, and it could also play an important role in the development of AS

Table 8
Estimated coefficient for the ML – model 4.

Variables	*Alternatives*						
	PC	Taxi	Train	PT	AS 2	AS 3	AS 4
TTT (h) mean	−7.12 (−4.01)	−7.12 (−4.01)	−7.12 (−4.01)	−7.12 (−4.01)	−7.12 (−4.01)	−7.12 (−4.01)	−7.12 (−4.01)
standard deviation	1.01 (3.82)	1.01 (3.82)	1.01 (3.82)	1.01 (3.82)	1.01 (3.82)	1.01 (3.82)	1.01 (3.82)
MC (€/100) mean	−9.98 (−4.21)	−9.98 (−4.21)	−9.98 (−4.21)	−9.98 (−4.21)	−9.98 (−4.21)	−9.98 (−4.21)	−9.98 (−4.21)
standard deviation	1.96 (3.75)	1.96 (3.75)	1.96 (3.75)	1.96 (3.75)	1.96 (3.75)	1.96 (3.75)	1.96 (3.75)
RP - C	/	/	/	/	−1.58 (−4.01)	−1.58 (−4.01)	−1.58 (−4.01)
Age <35	/	/	1.24 (3.74)	1.24 (3.74)	/	/	1.24 (3.74)
P	0.45* (1.76)	0.45* (1.76)	/	/	0.45* (1.76)	/	/
FF	/	/	/	/	/	/	1.25 (2.91)

* not significant at 5% level (*t*-test in brackets).
Adjusted $\rho^2 = 0.381$.
LL=-180.15.

systems as accustomed air travellers are more likely to use flying vehicles. This result is confirmed also by Model 4, where the coefficient value is quite equivalent to the first two models. Again, this could be useful to identify target groups to whom address primarily AS services.

Model 2 introduces a shadow variable for user's confidence towards automation and new technologies (AtoA), which should measure how and whether the experience with driving assistance systems could affect the willingness to use AS services. Although the coefficient is not significant at the considered level, however it emerges that a lack of experience with innovative systems could have a negative impact on the intention to use AS services. This has been found also for automated vehicles, both private and public ones, by confirming that user confidence in innovative systems is not immediate although safety standards are declared to be guaranteed.

From Model 3, an increasing ratio between the number of car and the driving license per family unit (CA) is a limit to the use of all the other alternatives, except, of course, private car. This confirms some other findings in the literature, as car ownership and private car use generally discourage travellers from choosing shared transportation modes. In other words, the comfort provided by private cars, even though affected by congestion issues and high management costs, overcome the potential benefits of other transportation modes, e.g. cheaper or more reliable modes. On the other side, the Occupation variable has a positive effect on the choice of transportation modes that might be more expensive but can reduce travel times, such as AS services or high-speed trains.

Although the variable related to travel reason (TR) resulted not significant at the considered level, however, the results show that users who travel for leisure tend to have a lower willingness to use AS services. This service would provide fast but expensive connections between airports and city centres, and it could be more suitable for business travellers.

Model 4 has allowed to analyse potential sample heterogeneity, particularly for time and cost variables – the same specification as in Model 1 has been used. Despite having a heterogeneous sample, the model confirmed the importance of travel time and monetary cost in choosing AS services. However, the coefficient values in Model 4 are definitely higher, in absolute value, than the ones obtained in Model 1, which is expected from previous literature results (see also Section 5).

Finally, the distance between the airport and the trip origin seems to have an important role for the development of AS services. In fact, the willingness to use AS systems rises as the distance increases. For shorter distances the advantages of AS services, mainly linked to the high cruise speed of the vehicles (and the possibility to fly over congested areas), are overcome by the increased time that users would experience at the vertiport and to reach the vertiport itself.

The obtained results suggest some strategies to design suitable future AS services. A first aspect is the importance given by younger people to service costs and the value of privacy for older users. This information can be used by stakeholders (especially service providers) to offer different types of AS services based on user categories. For example, it could be convenient to design shared runs targeted to young users having lower costs per passengers, which in addition can be useful to increase the load factor and maximize the revenues. Furthermore, before launching AS services stakeholders should evaluate users' satisfaction towards ground transportation modes that are potentially competitive with AS services in order to ensure suitable demand levels. Since leisure travellers seem less interested in AS services than business travellers, another indication is to schedule these services based on the departure of business flights, which are usually identified as those offered primarily by full-service airlines at a time that ensures return trips in the same day. It is worthwhile to note that business travellers are often frequent flyers with high-income occupation. Therefore, targeting these groups is also consistent with the findings that frequent flyers and high-level income workers are more likely to use AS services. Finally, the most suitable distance for offering AS services is more than 60 km from the airport. Nevertheless, the opportunity to skip airport security controls – and save time – because they could already be done at the vertiport could make even shorter connections convenient.

Although the results discussed in this section could be useful to identify the most important factors that stakeholders should consider to attract AS demand, however there are a few limitations affecting the study. The four models were calibrated by using SP data, which may suffer from some biases with respect to the calibrations obtained by RP data, as well-known from the literature on this topic. Furthermore, although the different models are specified with several socio-economic variables, however they do not include other variables that can affect users' choices such as security or safety or psycho-aptitude variables. Finally, the sample is mainly composed of young students or employees, while some other categories should be included for a wider estimate of the travellers' aptitudes.

7. Main findings and conclusions

New aerial transportation services promise to change the mobility of passengers and goods. However, still a few studies exist on this topic and there is high uncertainty on the impacts that could be generated by UAM systems. In addition, among the different studies on UAM passenger services, AS services are considered the ones with greater advantages, but only a limited number of studies focuses on the analysis of potential AS travellers.

This study has explored AS services in order to identify the main key factors driving users' choice. To this aim, a SP survey was carried out and three MNL models together with a Mixed Logit model were specified and calibrated. The results of the calibrations show that high ratio between car and driving licence per family unit and limited experience with driving assistance systems would limit the successful implementation of AS services. On the other hand, AS systems seem to be preferred by high-income people who travel frequently by plane. As for age, young people seem to prefer AS shared services in which the ticket cost can be divided with the other passengers, whereas older customers (more than 35 years) would prefer unshared AS alternatives. Finally, some inertia to shift towards advanced but still unknown flying alternatives lead travellers to confirm the choice of ground transportation modes they generally use, particularly for distances in the range 30–60 Km.

Starting from the results, averaged values of time (for the several transportation alternatives) have been estimated for the tested MNL models, which are quite in line with the results obtained in the literature for UAM services.

Future research will explore the importance of variables that were not considered in the presented model specifications, particularly safety and security issues could affect people intention to use AS services. Moreover, concerns about possible job loss risks due to the substitution of manned vehicles with unmanned ones and for passenger swich from conventional transportation services (e.g., bus, taxi) to AS services should be further investigated. In addition, environmental concerns such as the impact of drone production (and especially batteries), the impact on animal life and noise effects are aspects that can affect significantly AS choices by concerned people. Finally, higher demand levels, especially for shorter distances, could be obtained by realizing security and check-in operations at the vertiport, by designing suitable paths at the airport for reaching the gate directly. Future research should also focus on this aspect.

Authors contribution

All the authors reviewed and contributed equally to the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

Acknowledgments

The authors wish to thank two anonymous referees and the Editor that provided very useful comments to improve the paper.

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