User safety attitudes towards Urban Air Mobility

Annitsa Koumoutsidi, Ioanna Pagoni, Amalia Polydoropoulou

Department of Shipping, Trade & Transport, University of the Aegean, Korai 2a, Chios, akoumoutsidi@aegean.gr
Department of Shipping, Trade & Transport, University of the Aegean, Korai 2a, Chios, Department, Institution, ipagoni@aegean.gr
Department of Shipping, Trade & Transport, University of the Aegean, Korai 2a, Chios, polydor@aegean.gr

Abstract

Shared autonomous mobility has been in the spotlight of worldwide research during the last few years. In addition, the aim of safe, sustainable, environmentally friendly and comfortable transportation has led to several initiatives driven by the adoption of automation and electrification in urban mobility (e.g. autonomous and electric cars). However, a solution originates from the "third dimension" and the implementation of the unmanned aerial vehicle concept. This concept can be materialized by the innovative technology of electric vertical landing and take-off vehicles (eVToLs) to facilitate short-haul passenger trips and commutes in both urban and inter-urban environments. The aim of this paper shade light on the safety aspects of UAMs. It investigates individuals' concerns, perceptions, and attitudes towards the safety implications that arise from the implementation of eVToLs. To achieve this, a questionnaire survey is conducted, collecting disaggregate data from individuals regarding their socio-economic characteristics, current travel behavior and perceptions and attitudes towards safety. In addition, stated preference experiments are presented to capture individuals' mode choice behavior in the presence of eVToLs. A behavioral econometric model estimates passengers' probability to adopt eVToLs considering their safety perceptions regarding UAM. Major results include that travel cost and time plays important role in choosing transport mode, as well as automation and low environmental footprint positively affect people's choices for air taxis, while safety-related parameters that concern end-users seem to be crucial.

Keywords

Urban Air Mobility, Safety, End users' perception, Econometric Models

1. Introduction

Safety constitute two critical aspects to consider when implementing innovative technologies for transportation. Especially, in the field of autonomous mobility (either ground or air), safety-related issues should cautiously be investigated to enable its successful implementation, public acceptance and market acceleration. Considering the aviation industry over the past 20 years, aircraft and system malfunction has been minimized. However, human activity is still connected to errors and failures as current statistics indicate. On these grounds, autonomous air mobility could contribute to minimize human-related errors which are responsible for the 68% of air accidents (1). Urban air mobility (UAM) illustrates an initiative driven by the adoption of automation in mobility, while being materialized by the electric vertical landing and take-off technology (eVToLs) and facilitating short-haul passenger trips and commutes in both urban and inter-urban environments. European Union Aviation Safety Agency (EASA) imposes several obligations on the safety standards to certify eVToLs' production and operation, while several UAM companies have reassured fatal accident probability at less than 10^{-9} and safe land in case of various system failures (2).

To ensure UAM's efficient deployment, it is important to examine how its safety aspects might influence social acceptance and community engagement. Current studies on autonomous mobility indicate that people are generally concerned about the safety aspects of this new technology, while other have concluded that individuals' safety perceptions towards autonomy might impact social acceptance (3-8). A significant part of this literature focusing on ground autonomous mobility has indicated that positive safety perceptions towards AVs are linked to increasing individuals' intention to adopt AVs (9), while specific design characteristics and use cases might have different impact on people's perception (6,10). On the contrary, perceived safety risk may negatively affect AV acceptance (11) while early adopters seem to have positive perceptions of AV safety, maximizing future intention to use (6). Also, people living in developed countries (6) or in Western Europe countries (5) show less optimistic safety perceptions towards AVs.

Similar studies which investigate people's safety perceptions towards UAM have already been published. According to Eker et al. (4), Asian ethnicity and younger people have positive safety perceptions towards flying cars and security-related measures. EASA (12) provided proofs for the European community on UAM perceived safety related to the aviation safety levels, showing that citizens would trust UAM if it will be reassured that aviation levels will be applied in UAM too. Besides, people might be more reluctant towards this new mode, as they lack awareness and understanding of this concept, and they are not convinced of its benefits (13). A detailed analysis has been published by Rajendran and Srinivas (14) focusing on air taxi systems and associated operations while providing an extensive review of air taxi service developments and challenges that might emerge in the future. In general, few studies that have focused on the technical characteristics of eVToLs (15, 16), few others that have provided policy insights towards the aerial vehicle concept in terms of the related to infrastructure requirements (17) and environmental footprint (18), while the research field on safety and security issues regarding air taxis is under-researched (1,19).

Although the above indicate a growing literature on safety and UAM, few studies have investigated potential demand for flying cars with the consideration of users' attitudes and perceptions towards safety. Some researchers analyzed individuals' willingness to use (20) and pay (8) for air taxis, demand, and competition (21) as well as the future sustainable business models for their implementation (22). Stated preferences experiments have also been used to estimate preferences towards such an innovative technology. Lee et al., (23) have analyzed mode choice behavior for remotely piloted aircraft, while, Al Haddad et al. (24) pioneered by investigating the impact of key factors on the adoption of urban air mobility. The survey study explored travel behavior, current level of satisfaction with public transport system, and attitudes towards automation. It was observed differences in attitudes towards trust in automation, enjoyment of automation, perceived usefulness of UAM among individuals. Focusing on end-users willingness to use and pay for the eVToLs, Winter et al. (20) studied consumers' willingness to fly with autonomous air taxis. They conducted a questionnaire survey and collected data from 510 people. Their results showed that familiarity with air taxis, value in terms of benefits regarding the use of air taxis, feelings of happiness, and fun factor scale flying with air taxis were all positively related to willingness to fly, while wariness of new technology and fear had a negative impact. Similarly, Ahmed et al. (25) explored the willingness to hire and pay for flying taxis and shared flying car services through an online survey. It was found that respondents' age and cost-related concerns have overall homogeneous negative effects on various willingness to pay scenarios, while perceived benefits including lower and more reliable travel time, fewer and less severe crashes, more in-vehicle non-driving activities, less CO_2 emissions have a positive effect.

The aim of this paper is to enhance the above literature, by investigating individuals' concerns, perceptions and attitudes towards the safety implications that arise from the implementation of air taxis. To achieve this, a questionnaire survey is conducted, collecting disaggregate data from individuals regarding their socio-economic characteristics, current travel behavior, perceptions and attitudes towards safety . In addition, stated preference experiments are presented to capture the individuals' mode choice behavior in the presence of air taxis. A behavioral econometric model is developed to estimate passengers' probability to adopt air taxis considering the associated safety challenges.

2. Methodology

The methodology of our research is focused on discrete choice analysis. For this purpose, we conduct a questionnaire survey which collects both revealed and stated preference data, as well attitudes and perceptions for safety of UAM. By collecting perceived safety opinions, socioeconomic characteristics and preferences towards air taxis, we estimated a mixed logit model to predict potential demand, as well as to identify what are the key safety-related features that could affect people's preferences in choosing such an innovative technology.

2.1 Survey Design

Our study is organized around an online survey implemented through Sawtooth software and distributed to Greek citizens. The survey's main purpose was to explore the factors that affect people's preferences and choices regarding UAM in comparison with traditional transport modes when travelling among islands. For this reason, the survey consisted of the sections of respondents' socio-demographic characteristics, attitudinal data, and a section with the SP experiments. At the beginning of the survey and in order to maximize the understanding of respondents towards the air taxi concept, a comprehensive description of UAM was provided. Air taxi was presented to the respondents as a future alternative transport mode that transfers people and cargo by air. They were also informed about some of the characteristics of this future mobility concept, e.g. that people book their trip via a smartphone app, they can conduct urban, inter-city, inter-island, etc. trips of up to 150 km, the air taxis can be electric pilotless or remotely piloted vehicles of 4 to 6 seats.

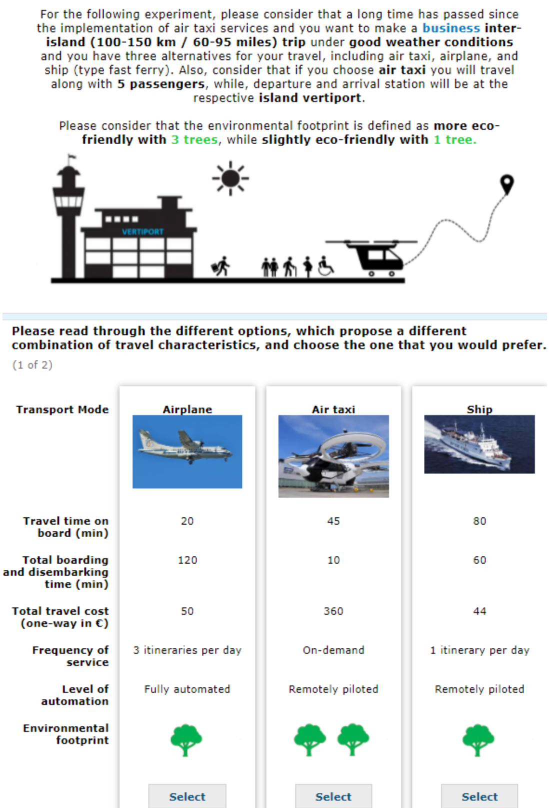

***Figure 1**: The Stated Preference*

Then, the survey participants were asked about their environmental and safety attitudes and perceptions and assessed them in a seven-point Likert scale with options ranging from "Strongly disagree" to "Strongly agree". All answers were verbally labeled as well as midpoints ("Neutral") as highlighted by Dolnicar (26). In this study, the safety statements are used to identify individuals' attitudes and perceptions towards air taxis for safety-related issues. In the section of the stated preference experiments, respondents were introduced with hypothetical scenarios of inter-city and inter-island trips in order to collect their preferences towards air taxis in comparison with other traditional modes of transport, as indicated in Figure 1. Each scenario concerned an inter-island trip of 100-150 km (60-95 miles) under good weather conditions. The respondents were presented with three alternatives for their travel, namely air taxi, airplane, and ship, considering that a long time has passed since the implementation of air taxi services. Each respondent participated in two unique task choices which differentiated in trip purpose either business (including education) or leisure. Also, in order to provide realistic scenarios a list of attributes was included with different levels in each transport mode, as depicted in the following table. Levels of each attribute are computed based on real paradigms of inter-island connections of 100-150 km in the Aegean Archipelago of Greece.

***Table 1:** Levels of the attributes used in the SP experiments*

	Air Taxi	Airplane	Ship
Time on board (min)	20;24;25;27;32;35;38;45	18;20;24;27;38;45;50	60;80;110;130;140;160
Boarding and disembarking time (min)	4;5;6;10;12;15;20	12;25;40;60;80;100;120;140	15;25;40;60;80;100;120;140
Total travel cost (one-way €)	120;160;180;240;360	50;72;89;120	30;37;40;44;50
Frequency of service	On-demand; 1 itinerary per day; 3 itineraries per day	1 itinerary per day; 3 itineraries per day	1 itinerary per day; 3 itineraries per day
Level of automation	Piloted; Remotely piloted; Fully automated	Piloted	Piloted; Fully automated
Environmental Footprint	🌳🌳;🌳🌳🌳	🌳	🌳;🌳🌳

In line with previous studies, the last part of the survey presented the socio-demographic questions, in order to prevent biased answers or avoid confirmation of any stereotypes (27,28).

2.2 Discrete Choice Model

In order to estimate individuals' choices for air taxis, airplanes, and ships, a discrete choice model is developed. More specifically the methodological framework (see Figure 2) is relied on the maximization of individual's utility when choosing an alternative (utility is depicted by an ellipse) considering the observable characteristics of the alternatives and other explanatory variables that represent individual's opinions for UAM safety and socioeconomic characteristics (alternatives' attributes, socioeconomic characteristics and safety-related opinions respectively depicted in rectangles). In our study, choice attributes include time, cost, automation level, service frequency and environmental footprint. The modeling framework is based on the generalized framework presented by Walker (29) and has been extensively used in modelling transport-related decisions and overall discrete choices.

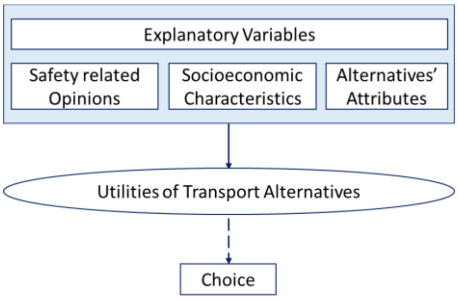

Figure 2: *Methodological Framework*

The utility functions of our choice model are specified in the standard linear-in-parameter form. Particularly, based on the utility maximization theory, a mixed logit model is developed to estimate the probability of individuals to choose a transport mode for their trip. Considering the novelty of air taxi, we first hypothesize that airplane and ship share unobservable attributes as they constitute traditional models for serving inter-island trips, so they are grouped in the "*Traditional Mode*" nest (see Figure 3). Additionally, it should be considered that air taxi and airplane might share some other unobservable attributes as they both serve aerial mobility, so it is more appropriate to be grouped in the "*Air Mode*" nest. The nesting structure of our model is depicted in Figure 3.

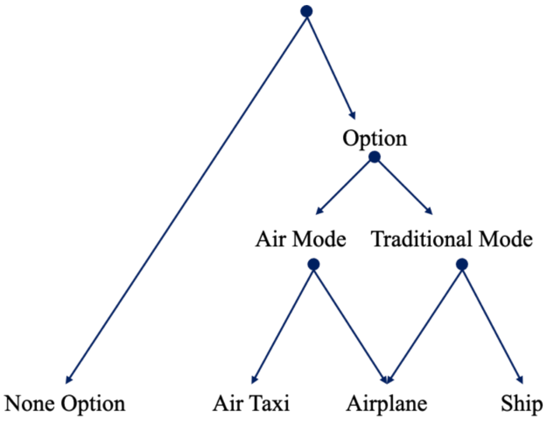

Figure 1: *Nesting Structure*

Eq (1) presents the general form of the utility function ($U_{i,n,t}$) derived from an individual *n* for each specific transport mode alternative *i*, and *t* indicates the SP task choice that each participant was requested to reply.

$$U_{i,n,t} = V_{i,n,t} + F * T * \zeta_n + \varepsilon_{i,n} = \beta * X_{i,n,t} + F * T * \zeta_n + \varepsilon_{i,n} \quad (1)$$

where $V_{i,n,t}$ is the deterministic or systematic part of the utility; $X_{i,n,t}$ is the vector of the observed variables; β is the vector of the coefficients of the observed variables in choice task *t* for person *n* to be estimated. The observed variables ($X_{i,n,t}$) represent the attributes of the alternatives that were presented to the respondents as well as the variables that capture participants' attitudes for air taxis related to safety.

To consider the panel effect of our data (i.e. the presence of repeated observations from the same individual) and the correlation among observations belonging to the same individual, we include in the utility function the error component (30). $\varepsilon_{i,n}$ is the random term of the model, to estimate the panel effect from the unobserved heterogeneity. Due to the assumption of Independence of Irrelevant Alternatives (I.I.A.) and to relax the independence between the unobserved components of the latent utility, a mixed logit model combining the nested model and error components was estimated. Considering two main nests on whether the individual made or not an option over the choice set, the rest nesting effects are captured by defining separate shared error components that account for the unobserved heterogeneity of the alternatives (31). More specifically (29),
ζ_n is (M x 1), M is the number of nests, and one factor is defined for each nest.

F is (J x M), $f_m = \begin{cases} 1\ if\ alternative\ j\ is\ a\ member\ of\ nest\ m, \\ 0\ otherwise \end{cases}$

T is (M x M) diagonal, which contains the standard deviation of each factor.

The indicator of the choice model is:

$$y_i = 1 \text{ , if } U_i = \max\{U_i\} \qquad (2)$$
$$y_i = 0 \text{ , otherwise}$$

where $i=1,\ldots,3$ in the choice set comprised of the three different alternatives i.

3. Analysis

3.1 Sample characteristics

Overall, the survey collected responses from 970 people, the characteristics of whom are presented in Table 2. The sample consisted of 63.8% females and 34.4% males, with an average age of 37 years and no difficulty to travel due to physical or health limitations (98.2%). Most of the participants hold a bachelor's degree (37.7%) or more (MSc and Ph.D. ~ 32.8%) and the majority are full-time employed (57.2%). A large percentage of the sample earns less than 9,100€ per year before tax (41.1%) or in the range 9,100 to 16,800€ (29.2%).

***Table 2:** Descriptive statistics of the survey sample (N=970)*

Variable	Category	%
Age	*Mean age*	**~37 years old**
Gender	Female	**63.80%**
	Male	34.40%
	Other	0.40%
	I prefer not to answer	1.30%
Educational level	Less than high school	0.50%
	High school graduate	20.40%
	Vocational	8.60%
	BSc degree	**37.70%**
	MSc or Doctorate	32.80%
Employment Status	Full-time employed	**57.20%**
	Part-time employed	6.50%
	Student	17.50%
	On furlough	2.60%
	Retired	3.90%
	Unemployed	8.00%
	Other	4.20%
Annual income before tax €	Less than 9,100	**36.30%**
	9,100 to 16,800	29.20%
	16,801 to 25,200	19.00%
	25,201 to 33,600	7.10%
	33,601 and more	8.40%

3.1 Model Specification

The actual choice of variables is limited by data availability and postulated based on a priori expectations. The model specification has been refined based on statistical tests on estimation results of alternative considered models. As mentioned above we identified correlation among alternatives due to sharing attributes. For this purpose, two error terms were estimated, EC_AIR and EC_TRA which assumed to be normally distributed. The utility function included both SP's attributes and dummy variables representing safety related attitudinal questions, as shown in the table 3. Concerning the attributes, the total time including embarking, disembarking and on-board time ($TOTIME_{AT}$, TOTIMEA, $TOTIME_S$) and cost ($TCOST_{AT}$, $TCOST_A$, $TCOST_S$) were included as scale variables and specific to each alternative. Also, the air taxis environmental footprint ($ENVFOOT_{AT}$) and automation level ($AUTOLVL_{AT}$) effect were estimated by including them as dummy variables, while the alternatives' service frequency (SERVFREQ) were included as dummy variable, estimating generic beta for the choice set. Additionally, several attitudinal questions were included as dummy variables concerning safety related issues for air modes. The fear of flying was included in both air taxi and airplane utility functions, specified to the relative alternative ($SF1_{AT}$, $SF1_{A}$), while air taxis' technological failures perception and fear of flying during the night explain air taxi utility (SF2, SF3). Socioeconomic characteristics had statistically insignificant results, hence they were excluded from the utility function.

Equation 4, 5, and 6 indicate the utility functions of the four alternative options:

$$U_{air\ taxi,n,t} = ASC_{air\ taxi} + \beta_{TOTIME_{AT}} * \mathrm{TOTIME_{AT}} + \beta_{\mathrm{TCOST_{AT}}} * TCOST_{AT} + \beta_{AUTOLVL_{AT}} * AUTOLVL_{AT} + \beta_{\mathrm{EVNFOOT_{AT}}} * ENVFOOT_{AT} + \beta_{SERVFREQ} * SERVFREQ_{AT} + \beta_{\mathrm{SF1_{AT}}} * SF1_{AT} + \beta_{\mathrm{SF2}} * SF2 + \beta_{\mathrm{SF3}} * SF3 + \mathrm{EC\_AIR} + \mathrm{Sigma\_panel} \quad (4)$$

$$U_{airplane,n,t} = ASC_{airplane} + \beta_{TOTIME_{A}} * \mathrm{TOTIME_{A}} + \beta_{\mathrm{TCOST_{A}}} * TCOST_{A} + \beta_{SERVFREQ} * SERVFREQ_{A} + \beta_{\mathrm{SF1_{A}}} * SF1_{A} + \mathrm{EC\_AIR} + \mathrm{EC\_TRA} + \mathrm{Sigma\_panel} \quad (5)$$

$$U_{ship,n,t} = ASC_{ship} + \beta_{TOTIME_{S}} * \mathrm{TOTIME_{S}} + \beta_{\mathrm{TCOST_{S}}} * TCOST_{S} + \beta_{SERVFREQ} * SERVFREQ_{S} + \mathrm{EC\_TRA} + \mathrm{Sigma\_panel} \quad (6)$$

$$U_{none} = 0 \quad (7)$$

where, the above explanatory variables are explained in the following table.

Table 3: *Variables and coefficients of the discrete choice model*

Variable Name	*Description of the variable*	*Coefficient*
$TOTIME_{AT}$	**Total Travel Time Air Taxi** *(Boarding, On Board, Disembarking; in min)*	$\beta_{TOTIME_{AT}}$
$TOTIME_{A}$	**Total Travel Time Airplane** *(Boarding, On Board, Disembarking; in min)*	$\beta_{TOTIME_{A}}$
$TOTIME_{S}$	**Total Travel Time Ship** *(Boarding, On Board, Disembarking; in min)*	$\beta_{TOTIME_{S}}$
$TCOST_{AT}$	**Travel Cost Air Taxi** *(in €; one way trip)*	$\beta_{\mathrm{TCOST_{AT}}}$
$TCOST_{A}$	**Travel Cost Airplane** *(in €; one way trip)*	$\beta_{\mathrm{TCOST_{A}}}$
$TCOST_{S}$	**Travel Cost Ship** *(in €; one way trip)*	$\beta_{\mathrm{TCOST}_{S}}$
$AUTOLVL_{AT}$	**Level of Automation** *(1 if air taxi is fully automated; 0)*	$\beta_{AUTOLVL_{AT}}$
$ENVFOOT_{AT}$	**Environmental Footprint** *(1 if air taxi has an eco-friendly operation; 0)*	$\beta_{\mathrm{EVNFOOT_{AT}}}$
$SERVFREQ_{AT}$	**Service Frequency** *(1 if air taxi provides one itinerary per day; 0)*	$\beta_{\mathrm{SERVFREQ}}$
$SERVFREQ_{A}$	**Service Frequency** *(1 if airplane provides one itinerary per day; 0)*	$\beta_{\mathrm{SERVFREQ}}$
$SERVFREQ_{S}$	**Service Frequency** *(1 if ship taxi provides one itinerary per day; 0)*	$\beta_{\mathrm{SERVFREQ}}$
$SF1_{AT}$	**"I am afraid of flying"** *(1 Yes, specific for air taxi; 0)*	β_{SF1}
$SF1_{A}$	**"I am afraid of flying"** *(1 Yes, specific for airplane; 0)*	β_{SF1}
SF2	**"I would worry about technological failures on the air taxi system/vehicle"** *(1 Yes, specific for air taxi; 0)*	β_{SF2}
SF3	**"I am afraid to use air taxi during the night"** *(1 Yes; 0)*	β_{SF3}
	Error Component capturing unobservable attributes that air modes share	EC_AIR
	Error Component capturing unobservable attributes that traditional modes share	EC_TRA
	Error Component capturing correlation from repeated observations	Sigma panel

4. Results and Discussion

Table 4 presents the estimation results of the mixed model. Starting with the error components (EC_AIR and EC_TRA), their statistical significance indicates that there is correlation between the presented alternatives (air taxi and airplane), thus, the use of a mixed model is reasonable. In addition, the error component Sigma_panel which is statistically significant indicates that there is serial correlation among observations belonging to the same individual.

Generally, all parameters of the model have reasonable signs, while almost all of them being statistically significant at 5% level. The alternative specific coefficients indicate that there is an intuitive preference towards the ship mode in comparison with the none choice (which is the reference option), followed by air taxi and airplane. Focusing on the attributes and as expected, travel cost and travel time have negative coefficients, indicating that as travel cost or time increases, the utility obtained from choosing this mode is likely to decrease. The coefficient of travel cost indicates that people are more sensitive to the prices of the ship mode (-1.670), followed by airplane (-1.320) and air taxi (-0.558). Similarly travel time shows strong differences among the alternatives. More specifically, the results indicate that individuals are more sensitive for travel time in choosing air taxi (-2.580), which is significantly different from zero, while much lesser on ship (-0.675) and airplane (-0.557). This may be explained by the fact that individuals are more time-sensitive, concerning the fact that air taxi constitutes a technological advanced air mode faster from the competing ones and could eventually save time. As for the environmental aspect of UAM, the positive sign of the environmental footprint variable (0.508) indicates that people are more likely to choose air taxis if the environmental impact is less than that of airplanes and ship. Additionally, the estimated coefficient of the variable “level of automation” (0.462) shows a positive effect of automation on people’s choices for air taxis and individuals express preference towards fully automated flights. Finally, the provided frequency of service (denoted as a dummy variable which represents the frequency of the service equal to once a day, against on-demand service and three times per day) appears to play a significant important role on people’s choices. More specifically, the negative sign indicates that fewer available itineraries per day would result to lower likelihood of choosing the alternative.

To further investigate the safety perceptions of people regarding air taxis, three dummy variables computed from the attitudinal questions are included as independent variables in our model. As expected, those who are afraid of flying (generic variable for air taxi and airplane) are less likely to choose air taxi or airplane as indicated by the related negative coefficients (-0.548). Additionally, as expected, those who would worry about technological failures on the air taxi system/vehicle (-0.632) and are afraid to use air taxi during the night (-0.548) are less likely to choose this innovative mode. The above findings are in line with the findings of previous research (25). They could also provide useful insights for policymakers and air vehicle manufacturers regarding the effect of air taxis’ safety aspects on public acceptance and adoption.

Table 4: *Choice model estimation results*

Name	Value	Rob. t-test
Air Taxi ASC	9.290	9.21
Airplane ASC	9.210	10.20
Ship ASC	9.680	9.50
$\beta_{TOTIME_{AT}}$ (air taxi)	-2.580	-2.73
$\beta_{TOTIME_{A}}$ (airplane)	-0.557	-3.24
$\beta_{TOTIME_{S}}$ (ship)	-0.675	-4.76
$\beta_{\mathrm{TCOST_{AT}}}$ (air taxi)	-0.558	-5.21
$\beta_{\mathrm{TCOST_{A}}}$ (airplane)	-1.320	-4.77
$\beta_{\mathrm{TCOST}_{S}}$ (ship)	-1.670	-1.63
$\beta_{\mathrm{EVNFOOT_{AT}}}$ (air taxi)	0.508	2.65
$\beta_{AUTOLVL_{AT}}$ (air taxi)	0.462	1.96
$\beta_{\mathrm{SERVFREQ}}$ (generic for choice set)	-0.232	-2.20
β_{SF1} (generic for air taxi and airplane)	-0.548	-2.48
β_{SF2} (air taxi)	-0.632	-2.73
β_{SF3} (air taxi)	-0.548	-2.70
EC_AIR	1.720	9.97
EC_TRA	-1.670	-8.28
Sigma_panel	3.370	6.05

Number of observations:	1865
Initial log likelihood:	-2.687.841

Final log likelihood:	-1.987.303
Likelihood ratio test for the initial model:	1401.076
Rho-square-bar for the initial model:	0.254

5. Conclusions

Urban Air Mobility is a novel concept of mobility that is expected to change the implementation of air mobility as it is currently applied. This paper investigated the factors affecting people's choices for air taxis, with a special focus on users' safety perceptions. Our results showed that, as expected, individuals are affected by travel cost and time in choosing transport mode. Two other important characteristics of air taxis include automation and low environmental footprint, both of which positively affect people's choices for air taxis. Concerning people's safety attitudes, our results showed that potential technological failures of air taxis are crucial safety-related parameters that concern end-users and affect their choices. In addition, fear of flying and flying with air taxi during night are key elements negatively affecting air taxis.

Further research should focus on enhancing the currently developed discrete choice model by developing a latent variable model. This could be done by incorporating the safety-related attitudes as latent variables in the utility function.

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