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EXECUTIVE SUMMARY OF THE THESIS

Discrete choice models to investigate travellers' intention-to-use Urban Air Mobility services

TESI MAGISTRALE IN MOBILITY ENGINEERING – INGEGNERIA DELLA MOBILITÀ

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1. Introduction

Urban Air Mobility (UAM) consists of new aerial transport services within and between cities employing electric aircrafts with Vertical Take-Off or Landing (VTOL) capabilities. The integration of these new services within the existing mobility system is one of the main challenges to be faced: UAM services need vertiports, i.e., VTOL take-off and landing infrastructures, for their operation and their locations must be optimally identified to complement current mobility system. [1]

On the demand side, travellers' adoption and intention-to-use these new services must not be taken for granted and this work aims at investigating factors affecting users' choice in the presence UAM airport shuttles or metropolitan taxis.

The remainder of this extended abstract is organized as follows. A review of the UAM literature, focusing on UAM ecosystem, potential impacts, and barrier for the implementation of this new aerial services is presented in Section 2. A brief description of both data and methods used is given in Section 3, while results from the application to the Milan metropolitan area and Lombardy Region are presented and discussed in Section 4. Concluding remarks are finally reported in Section 5.

2. State of the art

To understand the status of the UAM industry, its solidity and its development perspectives, businesses working in the UAM market were surveyed and a database containing information over more than 170 companies was populated. The total market capitalisation is higher than 900 billion USD, while the workforce counts more than two million employees.

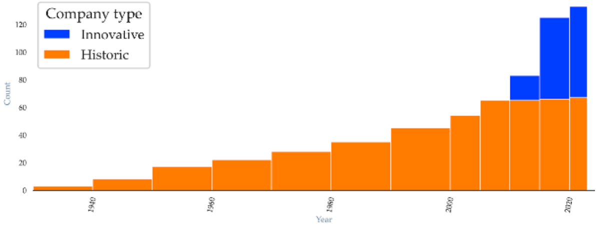

Figure 1. Number of companies by establishment year and type. Source: author's elaboration.

As reported in *Figure 1*, two clusters of companies can be identified: "Historic" and "Innovative" companies, being the latter category composed of businesses established specifically to work on UAM. Innovative companies are rapidly growing, but they cover only a small portion of the market: their total capitalisation is about 17 billion USD, and the total workforce is about 12.000 employees. In short, the UAM business panorama is characterised by numerous small, highly innovative, quickly growing start-ups, which, on the other hand, rely on historic companies to scale up their businesses.

To understand aircraft technologies which will be available for UAM services, a database consisting of more than 50 existing vehicles and prototypes was created. Supporting the claim that UAM is still an immature industry, only one aircraft is currently available for purchase, while seven others have applied for certification. The most used configuration is the tilt wing/rotor one (see *Figure* 2), while the favoured powerplant is battery electric (see *Figure 3*) and almost all the prototypes require a pilot to be on board.

Figure 2. Joby Aviation S4: example of tilt wing/rotor eVTOL model. Source: jobyaviation.com

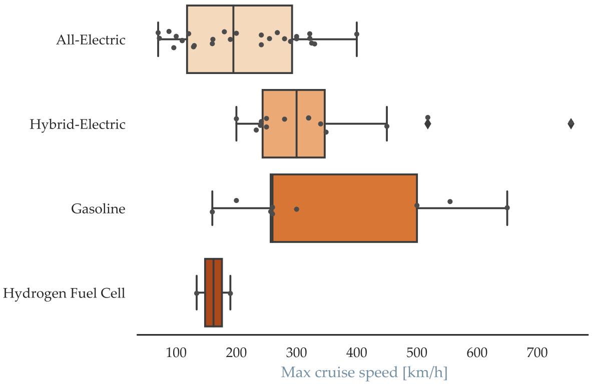

Figure 3. VTOL maximum cruise speed vs. powerplant. Source: author's elaboration.

The aircraft analysis has allowed to define three clusters of aircrafts, depending on their performance:

- Small multi-copters, with low speed (<150 km/h) and low range autonomy for intra-city use.
- Medium planes, with maximum speed higher than 300 km/h and a 200-300 km range autonomy for inter-city applications.
- Heavy long-range aircrafts for regional services, usually powered by conventional or a hybrid engine.

Regarding services, the types which are generally envisioned are intra-city transport, suburb/region-city transport and city-to-city transport, while the most frequently announced types of services are either airport shuttles or city taxis, with UAM service launches often coinciding with big events such as Olympic Games or Word EXPOs. These services are expected to be requestable via app, similar to conventional ride-hailing, or to be directly bookable together with a traditional plane flight, while there is still uncertainty about pre-flight security checks.

UAM physical infrastructure is composed of vertiports, or, in general, vertiplaces, which are the landing and take-off spots for UAM vehicles. These may vary depending on size and on the available facilities for passengers: from the smallest to the biggest, ranging from simple vertistops to vertiports (or vertibases) and big vertihubs. Much of the existing information and regulation about the set-up of vertiports is derived from helipads: the basic unit of any vertiplace is the TLOF (Touch down and Lift OFf) area, the place where planes land and take off, which must be enclosed in a FATO (Final Approach and Take-Off) area, a clear place used for final low-altitude VTOL approach. Another critical point related to ensure an adequate transport capacity, allowing safe and secure UAM operations, is the Air Traffic Management (ATM) system. Given the density of the areas over which UAM vehicles would operate and given the operations pace, the traditional voice-communication-based ATM would not be enough to manage all the air traffic. What is mostly proposed is separating traditional ATM from UAM: during an initial deployment phase UAM vehicles would fly only inside specific corridors or along fixed routes, while free flight will be available in the future. Moreover, UAM traffic would be managed by microservices, allowing aircrafts to communicate both among them and with a centralized server: no verbal communication with traditional air traffic control would occur, but all information about incoming flights (both UAM and conventional) would be only managed automatically.

The introduction of UAM services could generate impacts either closely linked to the mobility system or of a broader spectrum. After reviewing the literature, the followings have been identified as potentially predominant and have been thoroughly analysed in this thesis work: influence on travel time savings, ground congestion reduction, noise pollution, visual intrusion, labour market, urban development, and its environmental impact were studied. Only the first three are below briefly presented, having been demonstrated to be key for UAM success.

The impact on travel time and ground congestion has been highly debated. For instance, [2] found that UAM is convenient at most for trips in a range of 35-50 km, allowing for a travel time reduction of 3%-13% compared to ground modes. The estimated modal shift in trips from ground modes to UAM lies in the range 0.1%-6%, depending on the context, and so the positive impact on ground congestion will depend on the specific case study. Another relevant impact could be noise pollution: [3] computed that the intensity of noise emissions from UAM vehicles is lower compared to traditional aircrafts or road trucks. Despite this, the dense urban environment could amplify such intensity, leading to higher disturbance [4]; moreover, experiments have shown that, given the same noise emission intensity, people find UAM vehicles noise more annoying than airplane or road traffic noise [5]. Therefore, this could represent one of the barriers to public acceptance of these new services. However, looking at users' intention-to-use UAM, there are still other factors that are currently underexplored in the literature and are worth investigating.

3. Methods

To explore users' intention to use UAM services, a discrete choice modelling approach relying on the Random Utility theory ([6], [7]) was used. Particularly, three different modelling specifications were employed in this work: Multinomial Logit (MNL), Mixed Logit (ML) and Hybrid Choice (HC) with latent variables (LVs) models. In a MNL model, the probability that user n chooses alternative i in choice situation t is given by:

$$P_{i,n,t} = \frac{e^{V_{i,n,t}}}{\sum_{j=1}^{J} e^{V_{j,n,t}}} \qquad (Eq.\ 1)$$

where $V_{i,n,t}$ is the systematic component of utility:

$$V_{i,n,t} = ASC_{i,n,t} + \beta_{i,n,t} X_{i,n,t} \qquad (Eq.\ 2)$$

where $X_{i,n,t}$ performance attributes, $\beta_{i,n,t}$ the model parameters and $ASC_{i,n,t}$ the Alternative Specific Constants (ASC). Stochastic error terms in MNL models are assumed to follow a Gumbel distribution and to be independently and identically distributed (iid).

Using ML models, coefficients are no more necessarily constant but may follow a certain distribution, to account for taste heterogeneity between customers. Under this framework the probability that a user n chooses alternative j_n is:

$$P_n(j_n|\Omega) = \int_{\beta} P_n(j_n|\beta) g(\beta|\Omega)\, d\beta \qquad (Eq.\ 3)$$

where $g(\beta|\Omega)$ is the density of the distribution of β_n, a vector of the taste coefficients for consumer n. It is assumed that β_n is iid $\forall n$ over consumers and that Ω is a vector of parameters of the distribution g. Moreover, $P_n(j_n|\beta)$ gives the probability of the observed choice for consumer n, conditional on β.

The third category of tested specifications are HC models (schematically depicted in *Figure 4*): they are built by coupling a MNL choice model with a LV psychometric model. HC models take directly into consideration the cognitive workings that drive human behaviour, helping explain part of those choices which, only considering economic and demographic indicators, appear irrational. Structural equations, representing cause-effect relationships, link the observable socio-economic variables to the LVs, whose manifestations are user choices, while measurement equations link the LVs and the observable socio-economic variables to the indicators. Latent constructs are not directly observable, but their effect on indicators is, so that they allow the identification of latent constructs [8]. An example of indicators is responses to statements on a Likert scale.

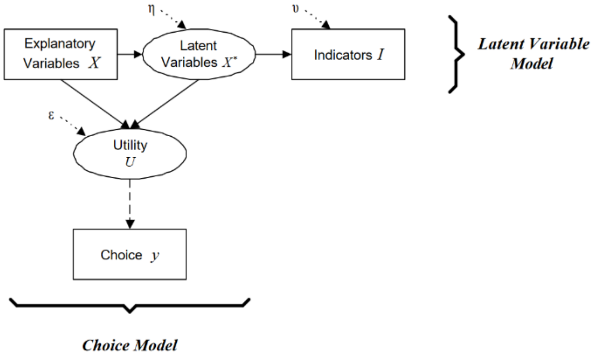

Figure 4. HC model framework. Ellipses represent unobservable (latent) constructs, while rectangles represent observable variables. Source: [8].

The utility function in a HC model becomes:

$$U = V(X, X^*; \beta) + \varepsilon \qquad (Eq.\ 4)$$

Where X are the observable attributes, X^* the LVs, β the vector of the coefficients and ε a random error term. LVs X^* can be expressed as:

$$X^* = h(X;\, \gamma) + \eta \qquad (Eq.\ 5)$$

where γ are the coefficients of the X variables and η is a random error term. In the LV model, the measurement equations have the following form:

$$I = g(X, X^*;\, \alpha) + \upsilon \qquad (Eq.\ 6)$$

where I is the vector of indicators, coefficients are named α and the error term is ν.

4. Application to the Lombardy Region and to the Milan metropolitan area

4.1. Data

Between December 2021 and January 2022, 2145 mixed Revealed (RP) and Stated Preference (SP) interviews were conducted; 1127 of these took place at Malpensa or Linate airports, while 1018 people were interviewed at major transportation nodes or touristic places of the Milan metropolitan area. The RP surveyed attributes were trip origin/destination, transport mode, travel time and monetary cost, trip purpose, trip frequency, availability of travel cost reimbursement and number of travel mates. If "Car" was the declared mode, the interviewee was asked whether he drove to the destination, whether the car was rented and about the parking duration. Regarding personal attributes, the following variables have been collected: car and driving licence availability, gender, age, degree of education, income, employment state, and family members. People were then requested to rate on a Likert scale (from 1 to 5, where 1 stands for "strongly disagree" and 5 "strongly agree") statements related to the fear of flying, enthusiasm for technology and UAM perceived safety. Regarding the SP experiments, travellers were asked to answer up to six different choice situations each, selecting the preferred transport mode among car, taxi, public transport (PT) and eVTOL, basing on travel time, monetary cost, access time and waiting/boarding time. Overall, more than 11.000 SP experiments were conducted.

Starting from the interviews database, Level Of Service (LOS) attributes of the non-chosen and currently available (i.e., excluding eVTOL) modal alternatives have been computed and added to the RP part: information was extracted from the Lombardy regional macro-simulation model available at the Department of Mechanical Engineering, in order to obtain the final LOS estimates. The resulting database was also filtered from irrelevant trips (i.e., trips not labelled as metropolitan or from/to airports) and a total of 1928 interviews have been subsequently analysed.

4.2. Modelling estimation results and discussion

Multiple models were fitted for both metropolitan and airport trips. In *Table 1*, the estimated beta parameters resulting from a ML model for airport trips are presented. In spite of minor differences, all results from the tested models are in agreement.

Parameters	Estimate	t-ratio	
Alternative Specific Constants			
Taxi RP	0,82	8,04	***
Taxi SP	-0,24	-3,07	***
PT RP	-0,02	-0,19	
PT SP	0,22	2,22	**
μ eVTOL	0,63	4,91	***
σ eVTOL	0,89	6,01	***
Level of Service attributes			
IVT (In-Vehicle Time)	-0,01	-5,64	***
OVT (Out-of-Vehicle Time)	-0,02	-4,40	***
MC (Monetary Cost)	-0,02	-6,54	***
MC (Monetary Cost) Business	0,004	3,76	***
Distance PT	-0,07	-2,18	**
Socio-economic and trip characteristic dummies			
Taxi: Education (≥ Master's)	0,21	2,53	**
eVTOL: Education (≥ Master's)	-0,13	-1,69	**
PT: Employment status (employed)	-0,07	-1,29	
PT: Travel expense refund available	-0,20	-2,22	**
eVTOL: Travel expense refund available	-0,06	-0,56	
PT: Annual income (>120 k€)	0,15	1,18	
eVTOL: Annual income (>120 k€)	0,73	3,90	***
PT: Malpensa airport as origin/destination	0,08	1,44	
eVTOL: Malpensa airport as origin/destination	0,35	4,00	***
Scale factors			
μ RP (constrained)	1,00	-	-
μ SP	2,65	5,83	***
Model performance indicators			
Rho-square	0,19		
Final-LL	6775		
Equal shares-LL (LL(0))	8378		
Sample size			
Observations RP	1048		
Observations SP	5305		

Table 1. Estimation results of a ML model for airport trips.

Considering all the tested systematic utility specifications for airport trips, the Value of Travel Time (VOTT) savings estimates, i.e., the ratio between in-vehicle time and monetary cost beta coefficients, lie in the range 40-75 €/h considering all travel modes and purposes other than business.

VOTT for business trips is generally 20%-50% higher than for other purposes.

The first proposed use case is UAM connecting Milan city centre and the airports in Malpensa and Linate. Along these links, PT is the preferred ground mode to reach airports, holding other variables constant, maybe thanks to the frequent direct bus connections linking Linate and Malpensa with Milan and thanks to the rail link to Malpensa. The ASC related to taxi is negative for the SP part, while it is positive for the RP one, potentially unveiling a preference of eVTOL with respect to taxis.

The models allow to make considerations also on the impact of factors other than pure level of service. If travel expense refund is available, the utility of PT decreases and so happens as distance increases: destinations far from the airport might be not well connected by PT, increasing the need for interchanges and the possibility of unpredictable delays. The type of origin or destination has an influence on mode choice: users find an advantage in using UAM to reach Malpensa airport, possibly because the destination falls in a convenient distance range. Another variable resulting to be significant is education: highly educated people (master’s degree or PhD) prefer using taxi, while they are less likely to use UAM. Besides, a factor favouring UAM adoption is a high personal income. Lastly, the availability of travel expenses reimbursement has a negative impact on eVTOL choice, which might be explained by limitations on travel budget imposed by companies.

In *Table 2*, results from a HC model estimation for metropolitan trips are presented. VOTT for eVTOL (37 €/h) is significantly higher than for other modes (Car&Taxi: 25 €/h, PT: 14€/h), which can also be reported for other models. VOTT for business trips is higher than for other purposes: this difference is less marked than for airport trips, suggesting it might be sensible to propose a pricing scheme for airport shuttle services which encompasses more levels depending on this customer segmentation.

Looking at the RP-specific ASCs, PT appears as the preferred option against car and taxi, whereas looking at SP-specific ASCs, it has been found that eVTOL is the preferred mode over all others. Considering the IVT coefficients for eVTOL, they are 50%-100% bigger in absolute value compared to ground modes, maybe for the eVTOL sense of insecurity and discomfort, making it unpleasant to spend time onboard. In addition, in other models considering mode specific betas for monetary cost, a different perception of it is recorded, highlighting a hierarchy of increasing quality of transport services: it is worst for cars and best for taxi, while eVTOL is regarded as slightly worse than taxi, probably for the comfort and safety concerns underlined above.

Parameters	Estimate	t-ratio	
Alternative Specific Constants			
Taxi RP	-0,31	-1,39	
Taxi SP	-0,93	-5,99	***
PT RP	1,28	9,70	***
PT SP	0,25	2,13	**
eVTOL	1,01		
Level of Service attributes			
IVT (In-Vehicle Time) Car-Taxi	-0,02	-9,56	***
IVT (In-Vehicle Time) PT	-0,01	-5,41	***
IVT (In-Vehicle Time) eVTOL	-0,03	-2,55	**
MC (Monetary Cost)	-0,04	-16,17	***
MC (Monetary Cost) Business	0,008	2,64	***
Distance PT	-0,14	-5,56	***
Socio-economic and trip characteristic dummies			
Taxi: Education (≥ Master's)	0,37	3,22	***
Taxi: Trip frequency (≥ 2/week)	0,41	3,38	***
eVTOL: Trip frequency (≥ 2/week)	-0,21	-1,18	
eVTOL: Gender (male)	-0,13	-0,21	
PT: Employment status (employed)	0,14	2,02	**
eVTOL: Employment status (employed)	-1,11	-1,55	
Taxi: Travel expense refund available	0,89	5,76	***
PT: Annual income (>120 k€)	-0,45	-2,49	**
eVTOL: Annual income (>120 k€)	0,56	1,07	
Taxi: Travels alone	-0,20	-1,35	
Latent variables			
Fear of flying	-0,12	-1,08	
Technology enthusiasm	0,44	4,91	***
eVTOL perceived safety	2,16	50,89	***
Scale factors			
μ RP (constrained)	1,00		
μ SP	1,13	17,95	***
Model performance indicators			
Rho-square	0,34		
Final-LL (choice model only)	4975		
Equal shares-LL (LL(0))	7510		
Sample size			
Observations RP	880		
Observations SP	4967		

Table 2. Estimation results of a HC model for metropolitan trips.

Turning to influence factors other than time and monetary cost, PT proved as less convenient for long distance travel and high-income people tend to use it less. People are more likely to use taxi if travel expenses are reimbursed, while they are less likely to do so if they travel alone, possibly because of the impossibility of cost sharing. Highly educated people are also more prone to choosing taxi. Regarding UAM services, it has been found that male travellers are more likely to use them, so are employed people and high-income ones, while the preferred adoption case is for non-recursive trips.

Additionally, interesting policy advice may be inferred using fear of flying, enthusiasm for technology and perceived eVTOL safety as LVs. Fear of flying has a negative impact on UAM choice, while enthusiasm for technology and perceived safety favour UAM use. The weight of perceived eVTOL safety is one order of magnitude higher than that of the other LVs: this could imply that it might be sensible to invest in improving the public perception of UAM to increase its modal share, even before working on performance. Differently, though, in the case of airport trips the weight of the LV "Perceived eVTOL safety" is reduced significantly. This might suggest that UAM safety is not much of a concern for people already used to air travel and, thus, that it might be sensible to prioritise investment in airport shuttles, as less barriers to adoption are in place.

5. Conclusions

This thesis work reviewed the UAM ecosystem, focusing on the business panorama, the aircrafts, the infrastructure, the potential services to be introduced and the control systems, the potential impacts, and the barriers for an effective UAM implementation.

Moreover, it focused on investigating factors that could influence users' intention-to-use UAM services for both metropolitan movements and airport related travels. Data from a large-scale mixed Revealed (RP) and Stated Preference (SP) survey from the Lombardy Region and the Milan area was analysed by means of Multinomial Logit, Mixed Logit and Hybrid Choice mode choice models.

Results indicate that level of service variables (i.e., travel times and monetary cost), socio-economic (such as gender and gross yearly income) and trip characteristic dummies (such as distance and travel expense reimbursement availability) are significant in explaining users' intention-to-use UAM. Moreover, the statistical importance of individual latent traits (fear of flying, technology enthusiasm and perceived eVTOL safety) influencing UAM choice has been proved, suggesting that the introduction of new and disruptive mobility services should be investigated not just considering "traditional pure utility components" (i.e., travel times and monetary costs).

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