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Potential market based policy considerations for urban air mobility

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A R T I C L E I N F O

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Demand estimation
Policy implication

A B S T R A C T

Urban air mobility (UAM) is a new concept in urban transportation systems; UAM employs an electric vertical takeoff and landing aircraft for operation in low-altitude urban areas. It complements the saturated conventional ground transportation systems in congested urban areas. The successful implementation of UAM as an urban transportation option necessitates the creation of appropriate policies and implementation strategies tailored to the UAM target market. This study aimed to provide policymakers with insights and policy implications based on a market analysis of the UAM. A stated preference survey was conducted with potential UAM users, and logit-based discrete choice models were developed. Subsequently, the models and actual traffic data were used to estimate the UAM demand in the Seoul metropolitan area in Korea, and the policy implications were derived, accounting for economic, social, and demographic factors. It was concluded that UAM policies should be tailored to the potential market for UAM, promote integrated mobility as a service, and enhance the social acceptance of UAM. Policymakers can use the results of this study to formulate necessary regulations and infrastructure for facilitating efficient and effective UAM integration.

1. Introduction

The continued increase in the population of urban areas is rendering them denser and more saturated. Consequently, urban areas have become more congested, resulting in several problems, such as air pollution and increased economic costs owing to increased travel time. To address these issues, urban air mobility (UAM) has recently emerged as a novel transportation system concept. UAM typically uses electric vertical takeoff and landing (eVTOL) aircraft to transport passengers (and cargo) as a taxi-like on-demand service within urban areas (Federal Aviation Administration, 2023; Holden and Goel, 2016). UAM is expected to move passengers at higher speeds and avoid ground congestion. As a result, they can reduce greenhouse gas (GHG) emissions compared to conventional ground transportation systems (Cho and Kim, 2022).

Traditional aircraft are unsuitable for use in urban areas because they can cause extensive environmental pollution, such as noise and emissions, require a large area for takeoff and landing, and are more expensive to operate (Vascik et al., 2018). The advent of the eVTOL aircraft and advances in autonomous flight technology can resolve these issues and facilitate UAM services in urban areas. The electric propulsion system of an eVTOL aircraft can dramatically reduce noise to socially acceptable levels compared to conventional rotorcraft (Holden and Goel, 2016; Cohen et al., 2021). This will also reduce the GHG emissions, rendering the UAM an environmentally friendly transportation system (Cho and Kim, 2022). The vertical takeoff and landing system of the UAM requires a smaller footprint than conventional fixed-wing aircraft, thus allowing the UAM to operate in dense urban areas, such as building rooftops or downtown heliports. Furthermore, UAM aims to fly fully autonomously (i.e., no pilot onboard); thus, their fares are expected to be reduced to reasonable levels (Goodrich and Theodore, 2021).

The successful implementation of UAM as an urban transportation option requires the formulation of policies and implementation plans tailored to the UAM target market. A proper target market analysis can aid policymakers and stakeholders in making regulatory, infrastructure planning, and operational decisions based on accurate traffic demand forecasts. Such an analysis is particularly important during the early stages of UAM deployment, as potential user behavior (e.g., mode choice and willingness to pay) cannot be observed until the UAM service begins.

Numerous countries have published plans and policy frameworks. In the United States, the National Aeronautics and Space Administration (NASA) has developed a mission of advanced air mobility (AAM). NASA has pursued a National Campaign to develop and validate system-level AAM concepts. NASA also conceptualized the UAM maturity level (UML) from UML-1 to UML-6, representing the stages of the UAM

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ecosystem (Hill et al., 2020). The Federal Aviation Administration announced its UAM concept for high-density urban operations from the near term to the future (Federal Aviation Administration, 2023). In the Republic of Korea, the Ministry of Land, Infrastructure, and Transport published a roadmap for UAM to establish its operational concept (Ministry of Land, Infrastructure, and Transport, 2021). In addition, a Grand Challenge demonstration program is conducted to validate the safety and traffic management of UAM in urban areas.

A new transportation market (e.g., UAM air taxi services) can be stimulated by strong policies such as the UAM roadmap of the Korean government, which demonstrates its strong intention to promote the UAM market in Korea. However, there is still a need for complementary policies based on market analysis for UAM. This is because public policies influence the market economically, and the available budget is limited (Nelson, 1999; Rye et al., 2008; Rotaris and Danielis, 2014; Fu et al., 2020). For example, the construction of transportation facilities such as vertiports requires a significant amount of time and money. Owing to budget constraints, a facility implementation plan must be executed in an optimal and timely manner. An accurate and reliable analysis of the potential UAM market can provide tangible insights and practical considerations for policymakers, thereby enabling them to tailor their UAM policies based on market analyses. Therefore, this study analyzed the UAM target market by forecasting its demand using a mode choice model. Mode choice models were proposed and estimated through a survey of potential UAM users. Consequently, the UAM demand in the Seoul metropolitan area was analyzed based on the estimated models and actual traffic data. The UAM target market (e.g., promising routes and potential customers) was analyzed for various operational considerations such as pricing strategy and operational characteristics. Finally, policy implications and considerations were determined based on the UAM target market analysis.

The remainder of this paper is organized as follows. Section 2 summarizes the previous studies on UAM policy and demand. Section 3 presents the mode choice models and analyzes the choice behaviors of potential UAM users. Section 4 proposes the policy implications and suggestions for the UAM, considering the choice model and demand estimation. Finally, Section 5 concludes the paper and suggests possible directions for future research.

2. Literature review

Since emergence of the concept of UAM, numerous studies have focused on the future transition of urban transportation systems caused by it (Garrow et al., 2021). Various frameworks have been used to study demand forecasting. Roy et al. (2021) proposed a methodology to estimate the potential user base of a business airport shuttle service employing a mode choice model. Bulusu et al. (2021) proposed a method to estimate the commuting traffic demand through comparisons of the time savings of multi-modal UAM with that of existing unimodal ground transportation. They applied this method to the San Francisco Bay Area and analyzed the demand changes with change in the travel and transfer times. Wu and Zhang (2021) estimated demand employing integer programming that minimized travel cost considering travelers' value of time (VOT) within the Tampa Bay Area, Florida. Rajendran et al. (2021) considered ride-related factors and weather-related variables as predictors of demand in New York City. They used and compared four machine learning algorithms (logistic regression, artificial neural networks, random forests, and gradient boosting) to predict the demand.

Stated preference (SP) surveys are widely used to observe choice behaviors in transportation, such as airline and airport choices (Hess et al., 2007), automated mobility-on-demand service preferences (Yun et al., 2022), remotely piloted aircraft preferences (Lee et al., 2019), and drone delivery preferences (Kim, 2020). Recent studies have attempted to apply the SP survey technique to UAM market studies and demand estimations. Fu et al. (2019) conducted an SP survey among autonomous flying taxis, public transportation, personal automobiles, and autonomous taxis in the Munich metropolitan region. Boddupalli et al. (2020) conducted an SP survey and estimated multinomial logit (MNL) models and mixed logit (ML) models for five cities in the United States. Cho and Kim (2022) estimated the MNL and ML models for urban and airport scenarios in the Seoul metropolitan area. Furthermore, they estimated the environmental impacts of the advent of UAM. Hwang and Hong (2023) also conducted an SP survey in the Seoul metropolitan area considering three different scenarios based on travel distance.

Studies focused on providing insights for policymakers are also being conducted based on choice-behavior analysis and demand estimation. Al Haddad et al. (2020) suggested policy implications based on the identifying factors affecting the adoption of UAM by conducting an SP survey and employing the technology acceptance model. They found that safety concerns were a crucial factor and proposed that policymakers should consider service attributes such as cost, time, access time, and sociodemographics. However, the SP survey in this study was not designed to investigate mode choice and presented only two alternatives (i.e., UAM and taxi). Therefore, they cannot provide quantitative insights into mode choice behavior or demand estimation. Rimjha et al. (2021) found that UAM demand is highly dependent on income level, fare, and trip delays. Policies for lowering fares and operational efficiency to reduce trip delays have been suggested to policymakers. However, the mode choice model employed is essentially calibrated for the existing transportation mode; therefore, it cannot appropriately capture the travelers' preferences for UAM.

To overcome the research gaps in previous studies, this study conducted a comprehensive process by estimating mode choice models that integrate UAM with existing transportation modes to provide quantitative insights for policymakers analyzing potential markets. Consequently, governments and policymakers can tailor their UAM policies based on an accurate and reliable market analysis of potential UAM services. The contributions of this study are fourfold.

- First, it proposed a mode choice model with high explanatory power that included personal automobiles, public transportation, taxis, and UAM as alternatives.
- Second, a survey questionnaire for model estimation was designed based on an analysis of actual traffic data in the Seoul metropolitan area, thereby facilitating a more accurate model.
- Third, the demand for UAM in densely populated and congested metropolitan areas was reliably predicted using actual traffic data.
- Finally, appropriate policy considerations were suggested based on the UAM market analysis.

3. Choice behavior analysis

This study proposed discrete choice models (DCMs) based on a logistic function to analyze the choice behavior of potential UAM customers. Such logit-based DCMs have been used for analyzing transport mode choices. They assume that people choose an alternative with the highest utility among the possible alternatives (McFadden et al., 1973). Because UAM is not currently commercialized, customer preferences are not observable. Thus, the mode choice behavior of potential UAM customers was estimated through an SP survey. Hypothetical situations were presented to respondents to explore the factors that influenced individual choice preferences, which is particularly useful when introducing a new mode such as UAM (Kroes and Sheldon, 1988).

3.1. SP survey

An SP survey presents a set of mode choice situations and asks respondents to choose the most attractive mode for each situation based on given conditions such as travel time and cost, which are

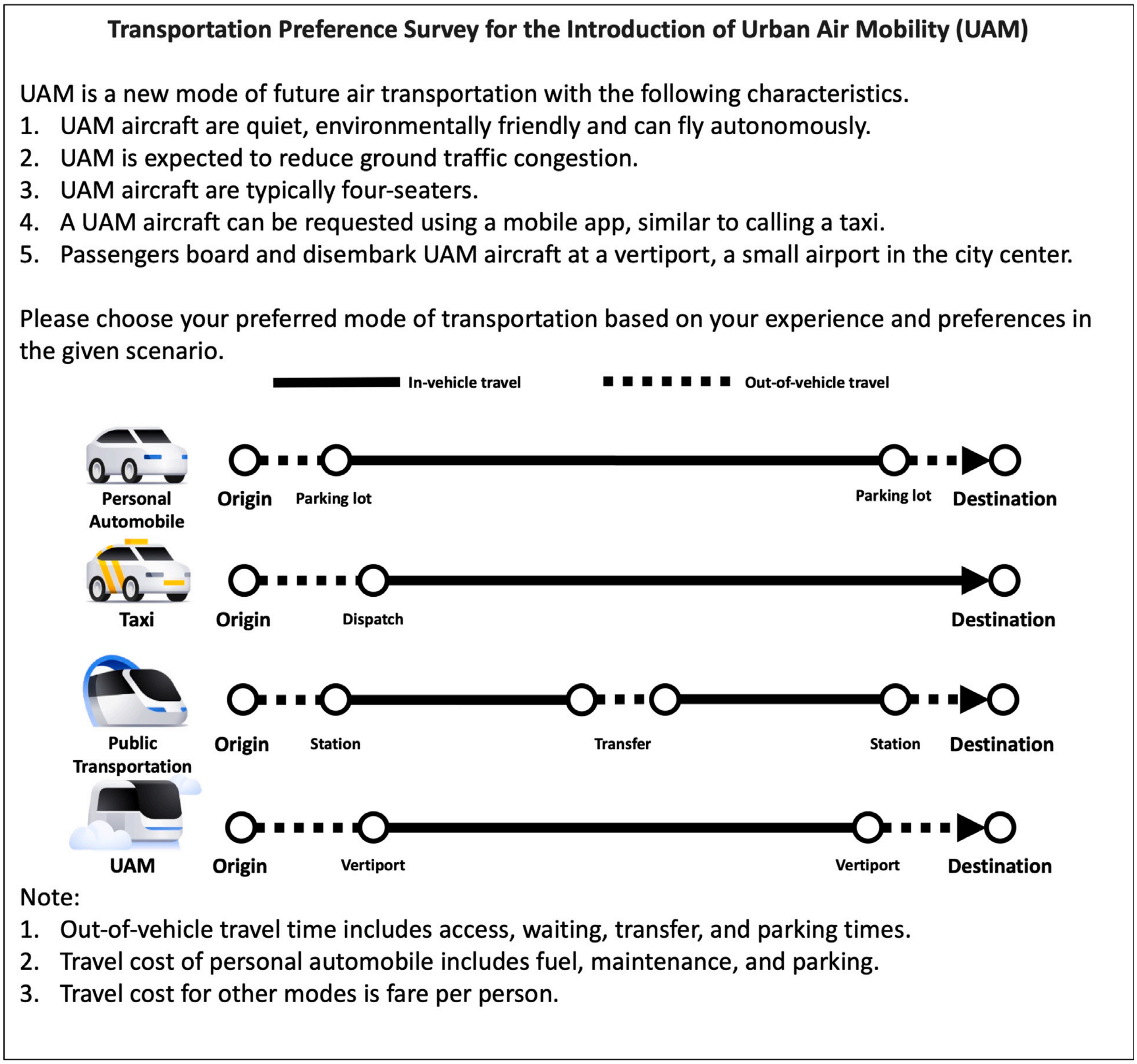


Fig. 1. Introduction page of survey questionnaire (translated from Korean into English).

dominant factors in mode choice behavior (Straubinger et al., 2020). Individual choice behavior is affected by alternative-specific attributes (e.g., time, cost, and frequency) and individual-specific characteristics (e.g., gender, age, income, and education), which are obtained through demographic and socioeconomic questions.

The introduction of the survey questionnaire explained the concept and illustrated the operation of UAM, as many respondents were unfamiliar with it. An introductory page of the questionnaire is shown in Fig. 1. In this SP survey, the UAM service was assumed to be an on-demand air taxi service within a metropolitan area. The aircraft used for this service was assumed to be electrically propelled, fully autonomous, and capable of vertical takeoff and landing. The web-based questionnaire included a short video clip introducing the concept of UAM to aid participants in understanding.

Owing to UAM being still unfamiliar to most people, the participants' answers may depend on the questionnaire. For example, regarding safety, a questionnaire may provide positive or negative information about the expected safety level of UAM. Perceptions and concerns about safety influence the choice behavior, particularly for new technologies such as UAM (Lee et al., 2019; Kim, 2020). Such perceptions are determined by (potential) users' acceptance of new technologies, and different groups of people would have different preferences for UAM. For example, early adopters may try UAM in the early stages, whereas conservatives wait until its safety is proven. However, owing to the lack of any safety record for UAM, providing a detailed description of its safety could potentially result in prejudice against UAM, resulting in biased responses. Therefore, the questionnaire did not describe the (expected) safety level of the UAM aircraft.

In addition, there exists a large gap between the actual level of safety and the public's perception of safety in air transportation. Elvik and Bjørnskau (2005) found that commercial aviation had the highest ratio of perceived risk to actual risk among transportation modes. Therefore, we described UAM as neither safer nor less safe than conventional air transportation to capture individuals' perceptions, regardless of the actual level of safety.

The SP survey included two scenarios: transportation within an urban area and transportation between an urban area and an airport. When people visit an airport, they usually fly to another city for vacations or business trips and return after a few days. Airport parking fees and varying quantities of baggage may cause people to make different choices when visiting airports. Therefore, the travel costs of personal automobiles were higher in the airport scenario than in the

Table 1
Levels of alternative specific variables (minute for time variable and USD for cost variable)

Scenario	Variable	Personal automobile	Public transportation	Taxi	UAM
Urban	Total travel time	50, 60, 70	–	50, 60, 70	10, 20, 30
	In-vehicle travel time	–	50, 60	–	–
	Out-of-vehicle travel time	–	20, 30	–	–
	Total travel cost	7.9, 15.8	1.58, 3.95	19.75, 27.65	39.5, 55.3, 71.1
Airport	Total travel time	40, 60	–	35, 55	10, 20
	In-vehicle travel time	–	30, 50	–	–
	Out-of-vehicle travel time	–	20, 30	–	–
	Total travel cost	19.75, 31.6	1.185, 6.32	11.85, 23.7	39.5, 55.3

urban scenario. However, the mode choice models in the next section aggregated both the scenarios because the aggregated models estimated the UAM demand more accurately than the disaggregated models.

Four alternatives – personal automobiles, public transportation, taxis, and UAM – were included in the survey, and their travel times and costs were varied for the model estimation. The values of the alternative-specific variables are listed in Table 1. The unit of the time variable was min, and that of the cost variable was US dollars (USD). Because the survey was conducted in Korea, costs were expressed in South Korean won (KRW) in the questionnaire. The dollar-to-won exchange rate was approximately 1266 in February 2023 (i.e., 1 USD = 1266 KRW or 0.79 USD = 1000 KRW).

Although an SP survey uses hypothetical situations, it should be designed as realistically as possible to facilitate the respondents in making reasonable choices that allow the resulting model to be validated (Kocur et al., 1981). Therefore, in this study, the scenarios in Table 1 were designed based on actual traffic data from the Kakao Mobility Corp., which is the leading transportation company in Korea and provides more than 90% of the taxi services in Korea (Dong-a Ilbo, 2023). The actual traffic data provided travel cost and travel time. The travel time for personal automobiles and taxis included access, in-vehicle, and egress times, whereas the travel cost for personal automobiles included fuel, parking, vehicle depreciation, and maintenance costs. This study used an online map service, such as Kakao Map, to determine travel times and costs for personal automobiles and public transportation. Notably, the travel time of public transportation is divided into in-vehicle time and out-of-vehicle time. This is because public transportation requires significant amounts of time to access, wait, transfer, and egress. Kakao Mobility Corp. provides in-vehicle and waiting times for taxis. To reduce the complexity of the survey and aid respondents in understanding mode-choice situations, the travel times for personal automobiles, taxis, and UAM were presented as total travel times. Notably, the taxis, public transportation, and UAM fares were per person.

The time and cost values in Table 1 were derived based on a preliminary analysis of promising routes for UAM services. First, the actual traffic data from Kakao Mobility Corp. were analyzed to identify the most popular routes at different times of the day, days of the week, and regions. Therefore, the most realistic travel times and costs were obtained for the representative routes. The travel time and cost levels were determined by considering the minimum, mean, and maximum values of the travel time and cost for each route. The survey design, based on actual data rather than approximate estimates, facilitated more accurate and robust models to understand the choice behavior of potential users (Fowkes and Wardman, 1988). The alternative-specific variables of personal automobiles, taxis, and UAM for the urban scenario differed at three levels for a more accurate estimation of the model, whereas the other alternative-specific variables differed at two levels for the efficiency and effectiveness of the survey questionnaire. The number of situations and level combinations were designed experimentally using a fractional factorial design. Consequently, 27 and 12 combinations (i.e., situations) of travel times and costs were obtained for urban and airport scenarios, respectively. Each respondent was provided both the urban and airport scenarios. Fig. 2 presents an example of a choice set in a business travel scenario.

The SP survey was conducted using the Kakao Mobility Corp.'s Kakao T, a total mobility application (Kakao Corp., 2024). Recent users of the Kakao T app, who had used it at least once in the past three months in the Seoul metropolitan area, were asked to participate in the survey. Korean mobility companies, including Kakao Mobility Corp., are planning to provide mobility as a service (MaaS) and consider UAM a promising transportation option. Therefore, mobility service users are expected to be the core customers of UAM. The survey was conducted in February 2023 and 717 respondents (342 non-business users and 375 business users) participated. Table 2 lists respondents' socioeconomic and demographic distributions. Because the survey was distributed to taxi users, the distribution of respondents differed from that of the actual population. In particular, high-income individuals were overrepresented. The estimated per capita income of Korea in 2021 is approximately 19.75k USD (Statistics Korea, 2022). This reflects a significant bias; however, the resulting models can accurately capture the choice behavior of high-income individuals, who are likely to be the primary customers of UAM given its high fares. Moreover, the user base of (on-demand) taxi services is expected to be similar to that of UAM services owing to the nature and strategies of MaaS.

3.2. Mode choice models

This study uses the SP survey results to estimate the MNL and ML models, which are commonly used DCMs (Garrow, 2016). Logit-based DCMs model individuals' probabilistic decisions using logistic distributions. They are based on the random utility theory, wherein individuals choose the alternative with the highest utility among possible alternatives, as mentioned earlier. The utility of alternative i for individual j is expressed as U_{ij} in Eq. (1), where V_{ij} and ϵ_{ij} denote observable and unobservable utilities, respectively. As ϵ_{ij} is not observable, it can be considered a random error.

$$U_{ij} = V_{ij} + \epsilon_{ij}. \quad (1)$$

Then, V_{ij} is expressed as follows.

$$V_{ij} = \mathrm{ASC}_i + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_n X_{ni} + \theta_1 Y_{1j} + \theta_2 Y_{2j} + \cdots + \theta_m Y_{mj}. \quad (2)$$

ASC_i is the alternative specific constant (ASC) of alternative i, representing the relative preference over the base alternative that is not explained by alternative-specific variables such as travel time and cost. $X_{\cdot i}$ and β are the alternative-specific variables of i and their coefficients, respectively. As indicated in Table 1, the travel time and cost are used as alternative-specific variables. $Y_{\cdot j}$ and θ denote the individual-specific variables of j and their coefficients, respectively. The demographic, socioeconomic, and personal attributes are used as individual-specific variables.

The probability that individual j chooses alternative i in the MNL model is expressed as Eq. (3). Because the MNL model assumes the irrelevant alternatives as being independent, it is simple. However, it has the drawback of imprecise estimation.

$$P_{ij} = \frac{\exp(V_{ij})}{\sum_i \exp(V_{ij})}. \quad (3)$$

The ML model was developed to overcome the limitations of the MNL model by assuming that each individual's preferences may differ.

(scenario) You are planning to travel from your residence to Gimpo International Airport for 3 days unaccompanied trip for business purposes.

Given the travel times and costs for each mode below, **please select your preferred mode.**

	Private car	**Public transportation**	**Taxi**	**UAM**
Travel time	60 min	In-vehicle 50 min Out-of-vehicle 20 min	35 min	20 min
Travel cost	40,000 KRW	1,500 KRW	30,000 KRW	50,000 KRW

Fig. 2. Example of a mode choice scenario (translated from Korean into English).

Table 2
Socioeconomic and demographic distribution of respondents.

	Category	Non-business		Business		Total	
		Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Gender	Male	159	46	138	37	297	41
	Female	183	54	237	63	420	59
Age	<20	1	0	2	1	3	0
	20–29	58	17	73	19	131	18
	30–39	124	36	184	49	308	43
	40–49	78	23	82	22	160	22
	50–59	68	20	24	6	92	13
	> 59	13	4	10	3	23	3
Annual income (USD)	<15.8k	46	13	17	5	63	9
	15.8k–31.5k	77	23	64	17	141	20
	31.5k–47.2k	65	19	85	23	150	21
	47.2k–63.0k	40	12	97	26	137	19
	>63.0k	114	33	112	30	226	32
Car ownership	Owned	97	28	130	35	227	32
	Not owned	245	72	245	65	490	68
Weekly taxi travel frequency	<2	268	78	241	64	509	71
	2–4	61	18	107	29	168	23
	> 4	13	4	27	7	40	6
Total	–	342	100	375	100	717	100

Accordingly, the ML model reflected the heterogeneity of potential customers. The probability of choosing alternative i for individual j in the ML model is expressed as Eq. (4); where $f(\beta)$ is the probability density function of β, which is assumed to follow a normal distribution in this study (Cho and Kim, 2022).

$$P_{ij} = \int \frac{\exp(V_{ij})}{\sum_i \exp(V_{ij})} f(\beta)\, d\beta. \tag{4}$$

The model coefficients (i.e., β and θ) of the MNL and ML models were estimated using *xlogit*, which is an open-source Python package that uses maximum simulated likelihood estimation, and the Broyden–Fletcher–Goldfarb–Shanno algorithm (Arteaga et al., 2022).

The estimated MNL and ML model results are presented in Tables 3 and 4, respectively. TT represents travel time, and TC represents travel costs. AIC and BIC represent the Akaike and Bayesian information criteria, respectively. The estimated coefficients are marked *** (p-value < 0.001), ** (p-value < 0.01), * (p-value < 0.05), and · (p-value < 0.1) according to their significance. Coefficients with p-values greater than 0.1 were excluded owing to their insignificance and marked as N/A (not applicable). Both models exhibited high McFadden R^2 values that measured the goodness of fit (McFadden et al., 1973). However, the ML model exhibited a better goodness of fit because it included individual-specific variables for demographic, socioeconomic, and personal perceptions. The coefficients of travel time and cost were negative for both the models, implying that travel time and cost were negatively correlated with utility, which is intuitive.

4. Results and policy implications

In this section, the choice model from the previous section is applied to estimate the demand for UAM. As a case study, the demand for UAM in the Seoul metropolitan area was estimated and several key insights into policy considerations were derived. The results of this case study are applicable to the Seoul metropolitan area and also to other congested metropolitan areas. In addition, the mode choice models presented in the previous section assumed that UAM was newly introduced; however, the models are sufficiently general to be used in the mature phase of UAM operations.

Various factors affecting the UAM demand were identified and analyzed to derive policy considerations based on the potential UAM user base. For this case study, the vertiport locations were selected from our previous work (Chae et al., 2023) and are shown in Fig. 3.

Table 3
Estimated MNL model.

Variable		Personal automobile	Public transportation	Taxi	UAM
ASC		N/A	−0.9268937***	0.8155668***	Base
TT (min)	Total	−0.0265438***		−0.0387031***	−0.0284752***
	In-vehicle		−0.0151427***		
	Out-of-vehicle		−0.0200282***		
TC (USD)		−0.0802016***	−0.0746080***	−0.0817309***	−0.0485884***
Log-likelihood		−11662.516			
AIC		23349.032			
BIC		23434.712			
McFadden R^2		0.4437442			

Table 4
Estimated ML model.

Variable		Personal automobile	Public Transportation	Taxi	UAM
ASC		N/A	N/A	0.6877744**	Base
TT (min)	Total	−0.0733591***		−0.0819895***	−0.0864710***
	In-vehicle		−0.0364423***		
	Out-of-vehicle		−0.0613894***		
TC (USD)		−0.2172114***	−0.1904225***	−0.1415976***	−0.1398211***
Purpose	Business	−1.0260045***	−0.9838016***	N/A	Base
	Non-business	1.1750736***	0.9466312***	0.5468995***	Base
Gender	Male	N/A	N/A	N/A	Base
	Female	0.3649300*	N/A	0.8611971***	Base
Age	<30	0.5154523***	−0.3572751*	N/A	Base
	30–39	−0.3069132**	−0.3456810**	N/A	Base
	40–49	−0.3009830*	0.5747648***	0.5298392***	Base
	>49	N/A	N/A	N/A	Base
Annual income (USD)	<15.8k	1.2437383***	2.6214732***	1.0963627***	Base
	15.8k–31.5k	N/A	N/A	N/A	Base
	31.5k–47.2k	0.3831507**	0.5230229***	0.6003054***	Base
	47.2k–63.0k	−1.0206446***	−1.7156476***	−0.4008560**	Base
	>63.0k	−0.5460218***	−1.6547691***	−0.4186069**	Base
Car ownership	Owned	0.8684792***	N/A	0.3029028*	Base
	Not owned	−0.7193824***	N/A	0.3848276**	Base
Weekly taxi travel frequency	<2	0.3739450**	0.3511096**	−0.2391659*	Base
	2–4	N/A	−0.6555135***	0.3417967**	Base
	>4	N/A	N/A	0.5851605***	Base
Factor to want to use UAM	Speed	−1.8376542***	−2.5469158***	−1.4861377***	Base
	Comfortability	−0.3094454**	−1.4877414***	−0.5998101***	Base
	Curiosity toward new technology	−0.6051236***	−0.3194761*	−0.2051682 ·	Base
	Eco-friendliness	−0.5379055**	−0.8660346***	−0.7094031***	Base
	Unusual view from above	0.5148265***	0.4536823**	0.2368928 ·	Base
Factor not to want to use UAM	Expensive fare	0.4457921**	0.4684642**	N/A	Base
	Safety concerns	N/A	N/A	0.2795669*	Base
	Satisfied with current transportation	0.6294080**	1.7804812***	1.5172934***	Base
	Inconvenience of access	N/A	−0.2809307*	N/A	Base
	Noise concerns	−1.2285280***	−1.6938023***	−0.8242310***	Base
Most considerable factor	Speed	N/A	−1.2341215 ·	−1.5163139*	Base
	Fare	1.7128312*	2.3307033**	N/A	Base
	Punctuality	N/A	N/A	N/A	Base
	Comfortability	N/A	−2.1707409**	N/A	Base
	Safety	4.2692956***	1.8808218 ·	1.8774479*	Base
	Accessibility	N/A	N/A	N/A	Base
	Views	N/A	N/A	−3.7510306**	Base
Log-likelihood		−7351.460			
AIC		14960.920			
BIC		15881.984			
McFadden R^2		0.6493645			

The vertiport locations in Fig. 3 were also determined using the actual traffic data used in the study. The UAM demand (i.e., the modal share of UAM) was estimated for all routes between vertiports using the ML model. The alternative-specific attributes (i.e., travel time and cost) were obtained from actual operational data as follows. The assumptions in Table 5 were considered based on the concept of operations in Korea (Ministry of Land, Infrastructure, and Transport, 2021). Despite the assumption of the UAM fare, the proposed mode choice models could adopt a cheaper fare base because the travel cost was a variable, as shown in Eq. (2).

- Personal automobile: Kakao Mobility Corp. navigation service data
- Public transportation: Kakao Maps service data

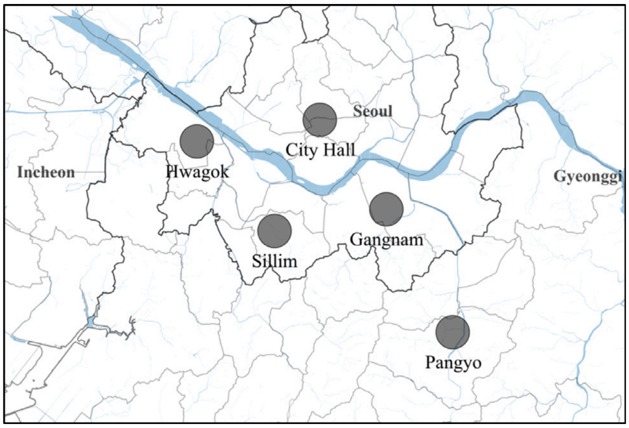


Fig. 3. Potential vertiport locations in the Seoul metropolitan area (Chae et al., 2023).

Table 5
UAM operational assumptions.

Attribute	Value
Catchment area	1.5 km radius
Circuity factor	1.4
Fare	3 USD/km
Transfer time	5 min
Cruising speed	200 km/h

Table 6
VOT derived from MNL model (USD per hour).

Variable	Personal automobile	Public transportation	Taxi	UAM
Total travel time	19.86		28.41	35.16
In-vehicle travel time		12.18		
Out-of-vehicle travel time		16.11		

- Taxi: Kakao Mobility Corp. on-demand taxi service data
- UAM: Assumptions in Table 5

Using actual travel time and cost data for ground transportation facilitated the estimation of UAM demand more accurately. In addition, because ground transportation involves very different travel times and costs depending on the time of day and day of the week, the UAM demand was estimated in four different time slots (i.e., weekday morning, weekday afternoon, weekday evening, and weekend). Passenger travel volume data from the Korea Transport Database were used to calibrate the total traffic volume (Korea Transport Database, 2020). In contrast to other alternatives, the UAM is not yet available, and the specifications of the eVTOL aircraft and regulations are opaque. Therefore, we assumed the major attributes of UAM to estimate the travel time and cost.

In the following subsections, the UAM share is defined as the ratio of UAM trips to total trips (or total traffic volume). The probability of choosing the UAM was calculated using Eq. (3). The UAM trip of an origin–destination (O-D) pair is the product of this probability and the total trips of the corresponding O-D. Notably, the total trips differed from one O-D to another O-D, and from time to time. Thus, the UAM share was the weighted average probability of choosing the UAM.

4.1. Economic considerations

Economic factors, such as UAM fare and individual income level, are the most important factors related to pricing strategy and economic policy for both the government and UAM service providers. Therefore, VOT was calculated to estimate travelers' willingness to pay. The VOTs derived from the MNL and ML models are presented in Tables 6 and 7, respectively. Both results indicated that the VOT of UAM was the highest, followed by that of taxis, personal automobiles, and public transportation. More specifically, the VOT of UAM is approximately two times higher than that of personal automobiles and even higher than that of taxis. This finding is important because the target market for UAM is likely to comprise people who value time highly (e.g., high-income earners). Therefore, current customers of premium taxi services such as Uber Black and Kakao T Black will be the primary target users of UAM; consequently, policy considerations should be made for this potential market of UAM.

Table 7
VOT derived from ML model (USD per hour).

Variable	Personal automobile	Public Transportation	Taxi	UAM
Total travel time	20.26		34.74	37.11
In-vehicle travel time		11.48		
Out-of-vehicle travel time		19.35		

The higher VOT of the UAM compared with the other modes is related to the individual-specific variable for annual income presented in Table 4. The group of respondents with an annual income level above 47.2k USD exhibited negative values (i.e., less preference) for personal automobiles, public transportation, and taxis. Thus, they preferred UAM to other modes of transportation. By contrast, those with lower incomes generally preferred other modes to UAM. In particular, those with an annual income of less than 15.8k USD indicated a very high preference for public transportation, that is approximately 13.7 times higher than that for UAM. Based on the income-related variables, people with an annual income of more than 47.2k USD can be considered as the target users of UAM. Fig. 4 shows the distribution of the population with an annual income of more than 47.2k USD in Korea. The total high-income population was approximately 1.9 million; however, it was mostly concentrated in the Seoul metropolitan area, where approximately 54% of the Korean population lives (Korea Culture Information Service Agency, 2023). Such economic power and high population density in the Seoul metropolitan area are favorable factors for the UAM market.

Fig. 5 shows the changes in the UAM demand based on the income level and UAM fare. The results indicated a significant increase in the UAM demand for income levels above 47.2k USD (Fig. 5(a)), regardless of the fare (Fig. 5(c)). This implies that the UAM is an attractive alternative for high-income earners, which is consistent with previous studies (Rimjha et al., 2021; Roy et al., 2021). In addition, for every USD decrease in the UAM fare per kilometer, the demand for UAM increased by approximately four times, as shown in Fig. 5(b). This result shows the importance of the pricing strategy for stakeholders. Subsidies can be considered to encourage a shift to UAM for environmental and congestion mitigation purposes. Further discussion on the environmental benefits is presented in this section.

Notably, the VOT of the out-of-vehicle time was higher than that of the in-vehicle time for public transportation. Thus, the access, egress, and transfer times are very important, even for public transportation. Moreover, it can be inferred that these out-of-vehicle times are also important for UAM customers. A previous study by Rimjha et al. (2021) showed that the UAM demand decreased as the travel delay increased. Specifically, a 10 min delay reduced the UAM demand by approximately half. A similar result was obtained in our case study in the Seoul metropolitan area. Fig. 6 shows that the UAM modal share decreased by approximately one-third for every five-minute increase in transfer time. Therefore, efficient operation and air-ground connectivity are important for promoting UAM services. The shorter the access, transfer, and waiting times, the more the number of people who will find UAM attractive.

In summary, the target market for UAM appeared to be high-income earners, given their higher VOT and preference for UAM. Based on

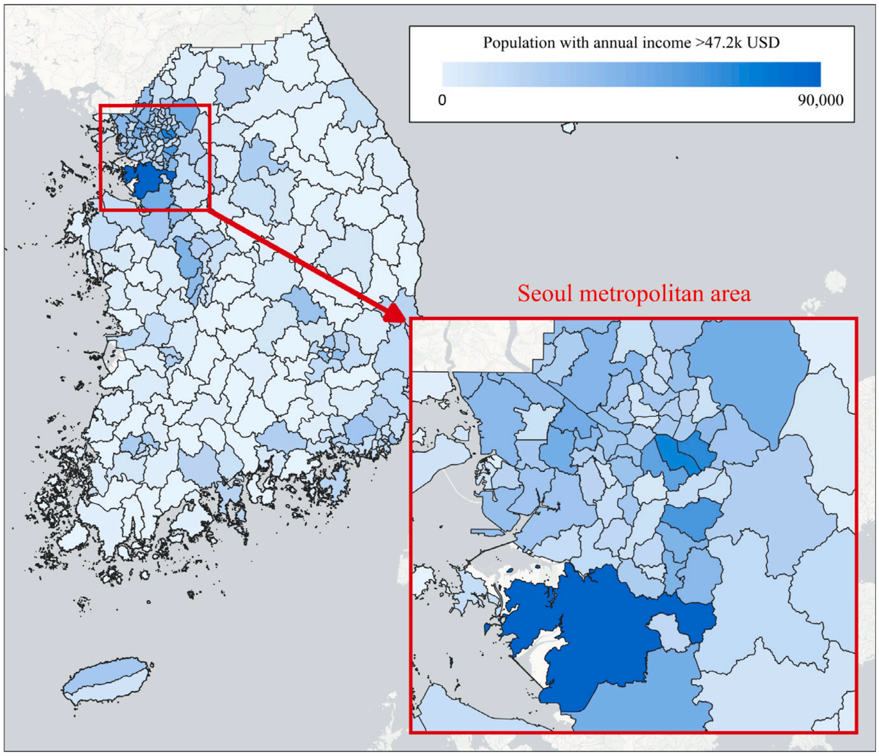
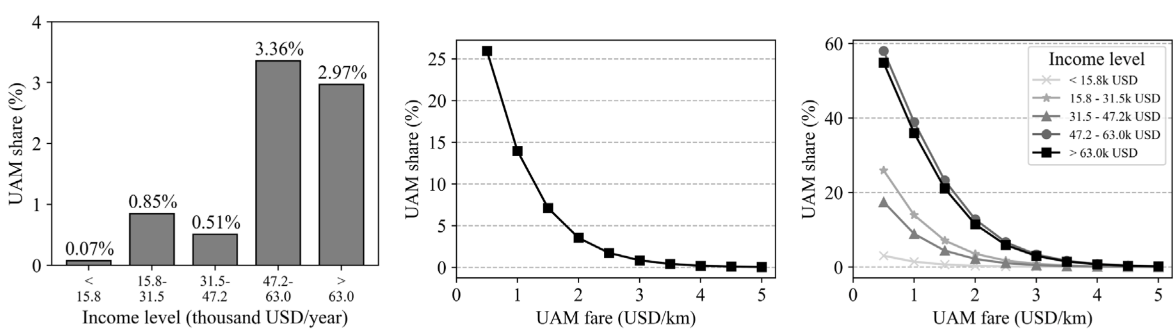


Fig. 4. Population distribution with annual income over 47.2k USD.



(a) Income level (b) Fare (c) Income level and fare

Fig. 5. UAM modal share by economic factors.

these findings, we proposed several policy implications. First, policymakers and UAM service providers must tailor their pricing and marketing strategies according to the potential user base. Considering the high VOTs and similar service attributes of UAM and taxis, the current policies and regulations for taxis can be used as a baseline for UAM. In addition, fare subsidies can incentivize the use of UAM to promote environmental benefits and mitigate congestion. Second, more research is required on the efficient operation of UAM. As observed in this analysis, unnecessary delays are detrimental to the utility of UAM services. Advances in air transportation systems can be adapted to UAM. This includes investments in infrastructure such as vertiports and airspace facilities. Considering the concentration of the potential user base in a congested metropolitan area, policy and infrastructure development can prioritize areas of economic strength. Finally, the UAM should be considered as a part of MaaS for seamless air-ground connectivity. Accordingly, policies must encourage integration between the UAM and existing ground transportation systems for efficient transfers and a convenient user experience.

4.2. Social acceptability considerations

The attitudes of potential users toward UAM (e.g., reasons for using UAM and considerations for mode choice) can aid in understanding the factors that people consider when choosing a transport mode. Social acceptance of UAM must be considered when formulating UAM policies. The factors for choosing the UAM, as shown in Table 4, indicate that the high speed of the UAM is more important than comfort, technical curiosity, environmental friendliness, or view. This is also related to the high VOT of the UAM: people who value their time the most want to use it. Therefore, the fast and efficient operation of UAM is a key factor in the UAM policy. In contrast, the view from above does not affect people's preferences for UAM.

Similar results were observed in Fig. 7, which shows the changes in demand for UAM for each attitude toward it. The UAM demand (i.e., the UAM modal share) was estimated for the vertiport network, as in Fig. 3. The results showed that the modal share of UAM was the highest for those who preferred high-speed UAM. Specifically,

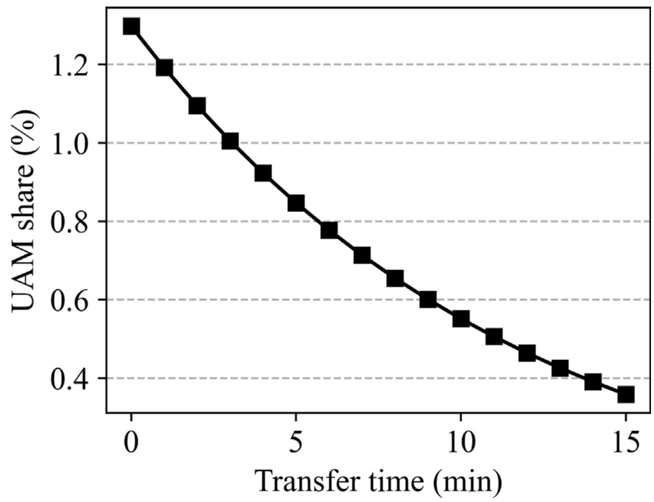


Fig. 6. UAM share by transfer time.

approximately 14 times more people chose UAM for its speed than for its view during flight. Therefore, speed is the primary factor influencing UAM demand.

The factors for not choosing the UAM, as shown in Table 4, indicate that many people are satisfied with the current transportation, particularly public transportation and taxis. The coefficients of the dummy variable corresponding to the preference for current (ground) transportation were significantly higher than those corresponding to UAM. As a result, only 0.16% of the people satisfied with their current transportation will choose UAM, as shown in Fig. 7. This tendency of continued preference for the current transportation is the same as that found in a previous Munich case study (Fu et al., 2019; Al Haddad et al., 2020), wherein public transportation users were least likely to shift from the current mode to UAM. This result provides important insights into the policy and strategy for UAM services in metropolitan areas with good public transportation systems. For example, the modal share of public transportation in Seoul was 65.6% in 2019 (Seoul Metropolitan Government, 2023) because Seoul has a highly advanced and inexpensive public transportation system that covers most of the metropolitan area, including 23 subway lines and hundreds of bus routes, as of 2023. Familiarity with the current transportation system influences the mode choice more than safety concerns or the high cost of UAM. Therefore, a public campaign to make people aware of and familiar with the new transportation service (i.e., UAM) is necessary to promote it in the market.

Finally, as shown in Fig. 7, potential UAM users considered speed and comfort to be the most important factors in choosing UAM. In contrast, people who rarely value (low or reasonable) fares and safety (i.e., less than 0.1%) chose UAM. Specifically, people who chose safety as an important factor exhibited a very low preference for UAM: they were approximately 6.5 times more likely to choose public transportation or taxis over UAM, and even 71.5 times more likely to choose a personal automobile. Thus, the main attraction of UAM is its comfort and faster speed, possibly because it avoids traffic congestion on the ground, while the biggest barriers to its social acceptance are its high cost and safety concerns.

In summary, understanding the attitudes of potential users toward UAM is a key driving element for the designing of effective UAM policies. Several policy implications were derived from this analysis. First, owing to the importance of familiarity with existing (ground) transportation systems, public awareness campaigns are required to introduce and familiarize potential users with UAM. This could help to overcome the preference for current transportation modes, particularly in areas with well-established public transportation systems. For example, NASA's National Campaign and Korea's Grand Challenge aim to demonstrate the feasibility of fully integrated UAM operations such that related information can be shared and exchanged with stakeholders. Consequently, the general public can become more aware of UAM, which will help them accept UAM in urban airspaces. Second, governments and aviation authorities should address safety concerns regarding UAM through regulations, industry standards, and public communication. Such resolutions should be incorporated well in advance before the initialization of UAM to prevent public fear of safety issues and help the public accept UAM as a new urban transportation system. Finally, along with policy implications regarding economic considerations, policies and regulations should focus on making UAM more affordable and efficient and emphasize the comfort and speed benefits of UAM in promotional efforts.

4.3. Demographic considerations

The demographic characteristics of potential UAM users are also important factors in UAM policymaking because they influence the VOT and attitudes toward a new technology (e.g., trust in a new technology) (Lee et al., 2019; Kim, 2020). Thus, the UAM demand was estimated for different demographic groups with different travel patterns.

This study categorized the purpose of a trip as business or non-business. Table 4 indicates that business travelers preferred UAM to personal automobiles and public transportation by a factor of approximately 2.7. By contrast, non-business travelers did not prefer UAM; their order of preference was personal automobiles, public transportation, taxis, and UAM. Consequently, approximately six times more people chose UAM for a business trip than for a non-business trip, as shown in Fig. 8. One possible explanation for this preference among

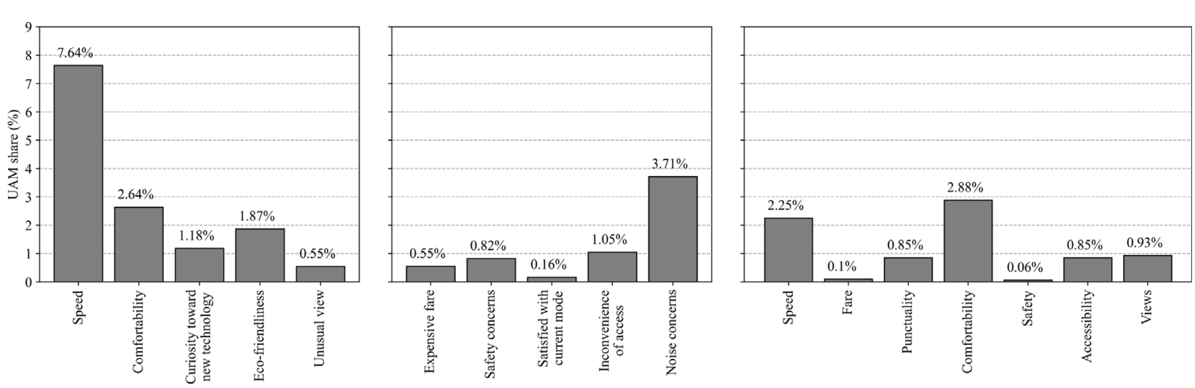


Fig. 7. Demand estimation by attitudes toward UAM.

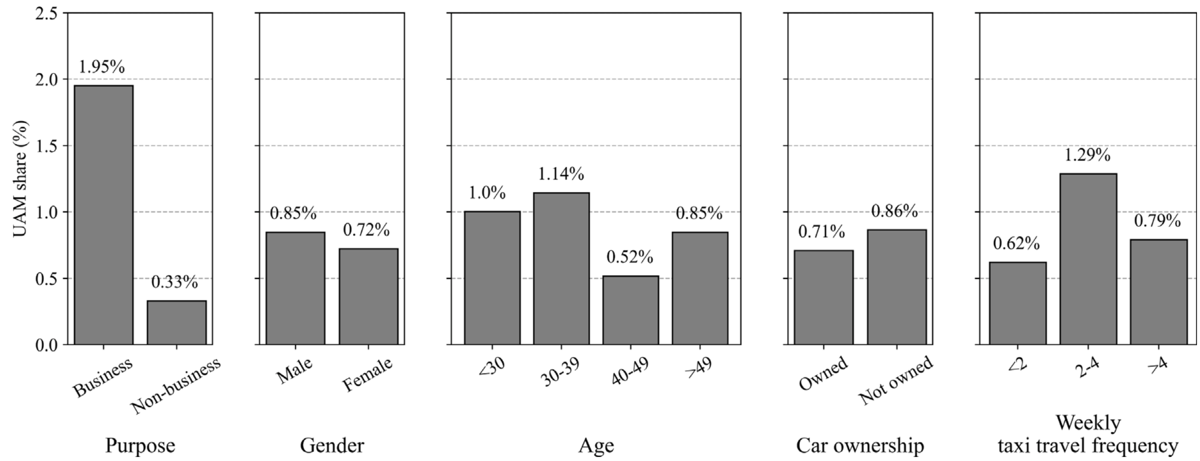


Fig. 8. Demand estimation by demographic and travel pattern attributes.

business travelers is that they value time over cost. It is also likely that companies pay for business travel; therefore, business travelers need not worry about the high cost of UAM and can choose a shorter travel time.

The preferences for UAM are not significantly different between males and females, as shown in Fig. 8. The male respondents exhibited no preference for one mode over the other; however, the female respondents preferred taxis and personal automobiles, as presented in Table 4. In contrast to the gender groups, different age groups showed different preferences for transportation modes. People under the age of 30 years indicated a high preference for personal automobiles. By contrast, people in their 40 s indicated a high preference for public transportation and taxis. No group had the highest preference for UAM over the other modes. Therefore, the 40 s group had the lowest modal share of UAM, as shown in Fig. 8.

People who own cars have a high preference for personal automobiles, whereas those who do not own cars have the opposite preference. Car ownership did not affect the preference for UAM over public transportation, as shown in Table 4. Accordingly, people who do not own a car are more likely to choose UAM than those who do. However, the difference is not large, as shown in Fig. 8. In contrast to car ownership, taxi usage patterns affect the preference for UAM, particularly over taxis. Table 4 shows that individuals who use taxis several times a week have a higher preference for taxis over UAM. As discussed earlier, the VOT of taxis was the second highest after the UAM. Given the relatively high taxi fare, similar service attributes (e.g., expensive, on-demand, and personalized) of UAM and taxis, and the preference for UAM among high-income earners, current taxi users are typically considered target users of UAM. However, taxi user loyalty may be a barrier to UAM adoption. Nevertheless, Fig. 8 shows the differences in loyalty among the taxi users. People who use taxis 2–4 times a week have a higher modal share of UAM than others. One possible explanation is that such people can afford the high fares of UAM and are satisfied with the service attributes of taxis (and also of UAM); however, they are not as loyal to taxis as those who take them more than four times a week.

In summary, demographic characteristics significantly influenced UAM demand; thus, several policy implications were drawn from considering demographic characteristics. First, UAM policies should be carefully tailored to different purposes. For business travelers, given their substantial preference for UAM, emphasizing its time-saving benefits can further boost its adoption. However, for non-business travelers, a different strategy and approach is needed. Based on the economic considerations discussed earlier, the willingness to pay in case of non-business travelers is likely to be lower than that of business travelers. Thus, financial approaches such as subsidies and incentives can be considered to promote UAM adoption for non-business travelers. Second, policymakers should focus on making UAM accessible to non-car owners as they indicated a higher preference for UAM than those who owned cars. Initiatives, such as integrating UAM into public transportation networks or providing special incentives to non-car owners, can encourage adoption. Further, seamless and integrated MaaS could be a good policy measure for UAM. Finally, a strategic approach and policy for the harmonized integration of taxis and UAM is necessary. As discussed, taxis and UAM share common attributes, such as high fare and service nature, and there is a potential conflict of interest between taxis and UAM. As shown in Fig. 8, high-frequency taxi users preferred UAM. However, UAM can complement taxis and not function as a substitute. Fig. 9 illustrates seamless multimodal MaaS proposed by Kakao Mobility Corp. When a user enters a destination, the MaaS platform provides several multimodal mobility options including air and ground. In particular, because UAM can move much faster than ground transportation, long-distance trips between vertiports will be made by UAM, and the first and last miles to and from the vertiports can be served by taxis. Thus, UAM and taxis are expected to be integrated into MaaS.

5. Conclusion

This study provided policy insights based on an analysis of the potential UAM markets. An SP survey was conducted and the DCMs were estimated from the survey results. The estimated DCMs were used to analyze the impact of economic, social, and demographic factors on the demand for UAM. Consequently, the overarching policy implications were derived by considering economics, social acceptability, and demographics.

The first policy implication was the need for tailored policies. The target market analysis in this study showed that high-income earners are the primary users of UAM, driven by their higher VOT and preferences for UAM services. Although high-income earners are the most prominent users of UAM, policymakers should make UAM more affordable for a broader user base such as non-business travelers. For example, financial incentives should also be considered. However, the government (and aviation authorities) should carefully analyze the impact, particularly the side effects, of such financial support and set long-term goals for UAM implementation.

The second policy implication was the integration into MaaS. Seamless air-ground connectivity is crucial for UAM implementation; thus, policies should emphasize facilitating the integration of UAM with existing ground transportation systems for efficient transfers and user-friendly experiences. Accordingly, UAM can become a core and integral component of MaaS. To facilitate integration, essential infrastructure is required and operational efficiency should be ensured. MaaS for UAM is beneficial for including non-car owners and taxi operators in the UAM

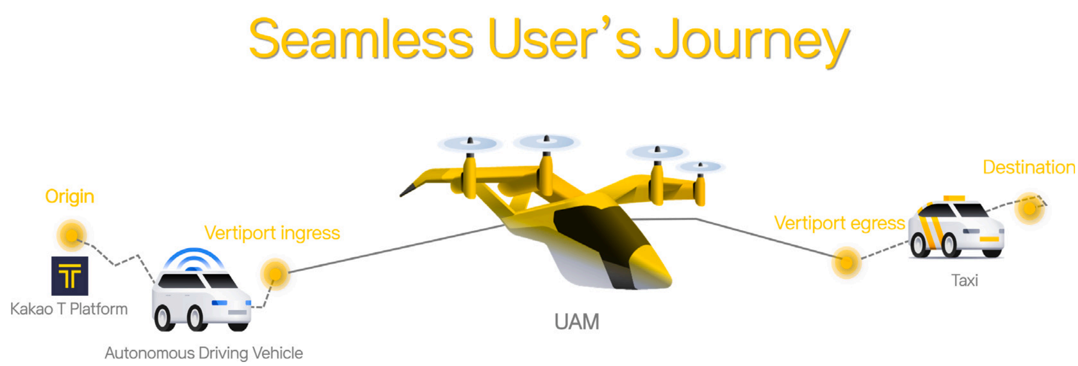


Fig. 9. Multimodal MaaS concept (Kakao Mobility Corporation, 2023).

ecosystem. It also aid in the maximization of the environmental benefits of the UAM, such as noise and emission reduction.

The final overarching policy implication was the importance of social acceptance. To increase the social acceptance of UAM, comprehensive public awareness campaigns focused on familiarizing the general public with UAM and emphasizing its benefits, safety features, and integration into existing transportation systems are required. Additionally, proactive measures to address safety concerns through regulations, industry standards, and transparent public communication are crucial. By building a positive and informed perception of UAM, policymakers can foster social acceptance and mitigate potential resistance to innovative urban transportation systems.

Overall, this study conducted a coherent analysis through a comprehensive process from survey to demand estimation, and derived insightful policy implications for policy makers. However, this study was limited by survey respondents, most of whom were active users of on-demand taxi services. Therefore, the survey responses may have been biased and not reflective of the entire population. The share of taxis in the Seoul metropolitan area, the region of interest in this study, is 3.2% on weekdays in 2022, which is lower than that of personal automobiles and public transportation (Seoul Metropolitan Government, 2023). Nevertheless, considering that UAM aims to be integrated into the urban transportation system as part of MaaS, this study is appropriate for estimating the demand of potential users for UAM, and the policy implications were tailored to the potential UAM market. Another limitation of this study was that the survey questionnaire did not provide detailed information on the safety of UAM owing the lack of safety records for UAM aircraft. As discussed earlier, perceived safety strongly influences choice behavior. Thus, future studies can improve the survey questionnaire and the resulting models to capture people's perceptions of UAM. This study was based on a case study of the Seoul metropolitan area; therefore, a future study will analyze the target markets of different metropolitan areas and examine the differences among areas.

CRediT authorship contribution statement

Munhyun Chae: Writing – original draft, Visualization, Formal analysis. **Sang Ho Kim:** Resources, Data curation. **Migyoung Kim:** Resources, Data curation. **Hee-Tae Park:** Resources, Project administration. **Sang Hyun Kim:** Writing – review & editing, Methodology, Funding acquisition, Formal analysis, Conceptualization.

Data availability

Some data is publicly available.

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