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A study on the factors influencing the adoption of urban air mobility and the future demand: Using the stated preference survey for three UAM operational scenarios in South Korea

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ABSTRACT

This study analyzed commuters' intention to use urban air mobility (UAM) and the future demand for UAM based on its service characteristics and the personal characteristics of the potential users. The Seoul Metropolitan Area (SMA) was selected as the study area as it is expected to have the highest demand for UAM in South Korea. Three UAM operation scenarios were set: short-distance intra-city trips, long-distance intra-city trips, and inter-city trips. Five alternatives were assumed for the stated preference (SP) survey: bus, subway, taxi, private car, and UAM. Six alternative-specific variables were selected: access time, waiting time, boarding time, cost, autonomous mode, and the presence of other passengers. An online survey of 300 residents of SMA was conducted with 100 residents for each scenario. The residents were briefed on the modes of transportation and service characteristic of alternatives. The analysis results were as follows: (1) cost and access time significantly influenced the intention to use UAM in all scenarios. However, the effects of waiting time, boarding time, and autonomous driving on intention to use UAM differed based on the scenarios; (2) the individual characteristics of potential users had varying effects on their preference for UAM depending on the scenarios and the means of transportation, which was a counterpart to UAM. (3) The probability of choosing UAM for commuting was expected to be 10–20%, with the highest modal split for long-distance intra-city trips and the lowest modal split for short-distance intra-city trips. Among the six alternative-specific variables, autonomous driving and cost had the most significant effect on the change of the probability for using UAM. The results of this study are expected to be used as basic data for designing an effective strategy for the introduction of UAM in South Korea.

1. Introduction

In recent years, interest in urban air mobility (UAM) has been increasing. UAM is recognized as an alternative to the existing ground transportation systems and is expected to offer various opportunities to achieve sustainable growth because of its following advantages.

First, UAM can expand the one-day life zone by reducing travel time as it moves in a straight line between origin and destination regardless of geographic features and surface traffic congestion (Kim, 2017; Serrao et al., 2018; Vascik et al., 2018). Second, UAM can be introduced at a relatively low cost because it does not require massive infrastructure, such as roads, bridges, tunnels, and rails. Furthermore, aircrafts with vertical take-off and landing features can take-off and land without runways, implying that UAM is available in built-up areas that may have insufficient ground space for construction of runways (Antcliff et al., 2016; Fadhil, 2018). Third, electrically operated aircraft, used for UAM, are eco-friendly transportation modes that do not emit carbon and generate less noise than motor vehicles (Fadhil, 2018; MOLIT, 2020).

Accordingly, numerous companies and governments worldwide have been increasing their investments in UAM (Fadhil, 2018; Vascik and Hansman, 2017). The UAM market is expected to grow to approximately \$50 billion–\$125 billion by 2030 (Goyal et al., 2018). South Korea is no exception to this trend. In 2018, the cost of traffic congestion in South Korea was 67.7631 trillion won (approximately \$57 billion),

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which is 3.6% of the GDP. This is far higher than that of the United States (0.9%), the United Kingdom (0.4%), and Germany (0.2%) (Korea Transport Institute, 2021). In this situation, UAM is expected to reduce, in the SMA, the average travel time by at least 40% at the peak time and the traffic congestion cost by 118.3 billion won a year (Song and Kim, 2017). Therefore, the South Korean government has announced a road map for K-UAM, a Korean-style strategy to introduce UAM.

For successful adoption of UAM in the future, it is crucial to identify the technical, institutional, and physical requirements for the UAM. Additionally, it is necessary to prepare an appropriate operation plan based on the knowledge regarding the determinants of the preference for UAM and the potential demand for UAM. Recently, an increasing number of studies have been conducted on UAM. Some have provided an overview of the current situation and future prospects of UAM development (Hwang, 2018; Jun et al., 2020; Rothfeld et al., 2020; Thipphavong et al., 2018). Several studies have focused on both UAM-related technology (Kohlman and Patterson, 2018; Shihab et al., 2020) and regulatory requirements (Bosson and Lauderdale, 2018; Cotton and Wing, 2018; Goodrich and Barmore, 2018; Serrao et al., 2018; Zhu and Wei, 2019). Numerous studies have presented the operation model (Lee and Hong, 2021; Thipphavong et al., 2018) or the possible location of infrastructures for UAM (Antcliff et al., 2016; Fadhil, 2018; Jeong and Hwang, 2021; Jung et al., 2021; Kim and Park, 2022; Lim and Hwang, 2019; Rath and Chow, 2021). Few authors (Garrow et al., 2021; Straubinger et al., 2020; Sun et al., 2021) have reviewed these literatures, identified the challenges in the successful adoption of UAM, and proposed future research directions for UAM.

Moreover, there have been attempts to forecast the demand for UAM. Some studies have simulated the number of trips and passengers for UAM (Balac et al., 2019; Fu, 2018; Pukhova et al., 2019; Rajendran et al., 2021; Rothfeld et al., 2018). Others have analyzed the attitude of the potential users towards UAM and the factors that may influence the preference for UAM (Al Haddad et al., 2020; Lineberger and Hussain, 2018; Lineberger et al., 2018; Reiche et al., 2018; Ward et al., 2021; Winter et al., 2020; Yedavalli and Mooberry, 2019). However, these studies were primarily focused on Western cities instead of Asian cities. The intention of using UAM may differ depending on the physical characteristics of the city and existing travel patterns of the residents. South Korea has a high density both in terms of population and physical structure as well as a well-connected public transportation system, including subways and buses, which are likely to influence the usage of UAM. Therefore, it is important to analyze the demand for UAM in the South Korean context.

This study aims to identify the factors that influence the willingness of residents in using UAM and estimating its potential demand in South Korea. In this study, we considered three types of UAM operation scenarios: (1) short-distance intra-city trips, (2) long-distance intra-city trips, and (3) inter-city trips. In each scenario, the effects of the socio-demographic characteristics of potential users, such as gender and age, and the service characteristics of UAM, such as time and cost, on the preference for UAM were analyzed. Furthermore, the probabilities of choosing subway, bus, taxi, private car, and UAM for commuting purpose and the marginal effects of UAM related attributes on them were studied.

2. Literature review

2.1. Challenges for successful UAM adoption

During the last decade, technological progress has brightened the prospects of UAM. Nevertheless, numerous challenges still remain for the successful introduction of UAM. One of the fundamental elements of UAM is a suitable aircraft (Straubinger et al., 2020). Various literature have discussed the requirements for aircraft and surveyed the development status of related technologies (Hwang, 2018; Jun et al., 2020; Rothfeld et al., 2020; Thipphavong et al., 2018). According to them, the distributed electric propulsion system is a core technology that can generate sufficient power for flight solely through electricity, thus enabling more efficient and low-noise flight (Jun et al., 2020; Thipphavong et al., 2018). In addition, battery technology plays a crucial role in terms of storing the electric power (Uber, 2016). Technology for reducing blade noise is essential for UAM operations in urban areas (Jun et al., 2020). Uber (2016) proposed a requirement of 62 dB at ground level from a vertical take-off and landing (VTOL) aircraft at 500 ft altitude. Additionally, the development of autonomous flight technology is necessary to operate a huge number of aircraft at low cost without the need for pilots (Jun et al., 2020).

One of the most significant challenges for UAM adoption is the legal and regulatory barriers (Serrao et al., 2018). Successful implementation of UAM requires safety standards and certification tools for aircraft (Straubinger et al., 2020). Recently, European Aviation Safety Agency (EASA) and the US Federal Aviation Administration (FAA) have considered regulations for certification (Straubinger et al., 2020). Additionally, regulations for crew training and licensing, operating organizations, and passenger safety and privacy are necessary requirements (Straubinger et al., 2020). In particular, the existing studies emphasize the necessity of regulations governing the airspace. Within the urban airspace, where high traffic density is expected, a specific system is needed to enable safe, efficient, and high-volume operation of UAM. Bosson and Lauderdale (2018) analyzed the existing legislation relevant to UAM and identified necessary regulations. Several studies (Bosson and Lauderdale, 2018; Cotton and Wing, 2018; Goodrich and Barmore, 2018; Zhu and Wei, 2019) have suggested the measures to regulate flight routes, departure and arrival schedules, and safe separation between aircraft within the airspace.

Other key drivers for successful UAM adoption are the operational concepts and business models of UAM (Straubinger et al., 2020; Sun et al., 2021). Thipphavong et al. (2018) presented three types of operational concepts: 1) emergent UAM operations, 2) early expanded UAM operations, and 3) mature UAM operations. In the early expanded UAM operations, UAM vehicles move between several takeoff and landing areas along fixed routes by low-frequency. Early expanded UAM operations have higher-frequency flights in a small network. Mature UAM operations have multiple hub locations, and UAM vehicles move between these hubs with high density and high-frequency. Lee and Hong (2021) classified the spatial range of UAM operation into three categories: intra-city trips, inter-city trips, and inter-region trips. Additionally, the authors proposed an implementation plan of UAM for passenger transport, suggesting the operation of airport shuttle and air metro in the initial stage, air taxi in the intermediate stage, and mobility as a service (MaaS) type UAM and personal air vehicle (PAV) type UAM in the final stage.

UAM aircraft requires ground infrastructures for take-off and landing, charging, and parking. Uber (2016) presented the concept of vertiports, vertistops, and vertihubs. Determining the location of such infrastructures has been a crucial issue in previous studies. Some studies suggested major roadway cloverleafs, barges over water, and rooftops of existing buildings as possible placements for ground infrastructure (Antcliff et al., 2016; Fadhil, 2018). Additionally, there have been efforts to find suitable locations for ground infrastructure. Antcliff et al. (2016) identified the requirements of ground infrastructures and found locations that met those requirements. Some researchers (Lim and Hwang, 2019; Jeong and Hwang, 2021) applied the K-means algorithm to commuting data to determine the geographical centers of clusters, which were then selected as suitable locations for vertiports. Jung et al. (2021) and Fadhil (2018) derived the weight of location factors based on expert evaluations using analytic network process (ANP) or analytic hierarchy process (AHP).

2.2. Public acceptance and future demand for UAM

To achieve successful UAM implementation, it is crucial to overcome the technological, regulatory, and physical hurdles and understand public attitudes towards UAM. UAM cannot be successfully implemented when there is a lack of willingness to accept UAM. Above all, it is necessary to identify and overcome the psychological barriers towards UAM (Lineberger et al., 2018). Previous studies (Al Haddad et al., 2020; Lineberger and Hussain, 2018; Reiche et al., 2018; Yedavalli and Mooberry, 2019) have identified safety-related issues as a major concern. Potential users, although expressing safety concerns (Lineberger and Hussain, 2018; Yedavalli and Mooberry, 2019), show the willingness to adopt UAM when safety is assured (Reiche et al., 2018). Furthermore, security and privacy issues were identified as critical psychological barriers influencing the acceptance of UAM (Reiche et al., 2018). Potential users consider the importance of time and money savings offered by UAM (Al Haddad et al., 2020; Reiche et al., 2018). In this regard, Winter et al. (2020) emphasized the significance of increasing familiarity and perceived value toward autonomous air taxis. Moreover, perceptions of UAM vary according to socio-demographics. Yedavalli and Mooberry (2019) found that men, young individuals, higher-income earners, highly educated individuals, individuals with longer commuting times, and urban dwellers tend to have a more positive view of UAM. Ward et al. (2021) demonstrated that consumer perceptions towards autonomous air taxis differ based on nationality.

Some studies (Balac et al., 2019; Pukhova et al., 2019; Rothfeld et al., 2018) have utilized simulation tools such as MAtSim to predict the demands for UAM. Balac et al. (2019) selected virtual vertiport locations within Zurich and estimated passenger flow within the networks connecting them. Balac et al. (2019) confirmed that process time, cruising speed, and cost per distance are factors that determine the flow of passengers. Additionally, Pukhova et al. (2019) examined the impact of process time, cruise speed, and travel cost on UAM mode choice in the Upper Bavaria region. In this study, travel cost was found to have the greatest influence on UAM modal share, while cruise speed had the least significant impact. Rothfeld et al. (2018) confirmed that process time, VTOL speed, and cruise speed were the determining factors for the number of UAM passengers in Sioux Falls. In particular, the authors mentioned that process time affected the UAM usage more severely than VTOL speed or cruise speed. In this study, the modal share of UAM was observed to be only 4%, indicating that 74% of individuals still opted for transportation by car. Cost is the most emphasized in existing simulation studies. When the cost is high, there is a possibility that UAM will be only perceived as attractive to the affluent population, thus limiting the user base (Balac et al., 2019). Kreimeier et al. (2017) mentioned that UAM costs should be lower than car costs in order to be competitive.

Fu (2018) employed the stated preference (SP) methodology to examine the determinants of selecting autonomous flying taxis. Similar to simulation studies, Fu (2018) found that travel time and travel cost influence the selection of autonomous transportation modes, while also discovering the importance of safety. Additionally, the study revealed that the younger and older individuals with higher incomes are more likely to actively engage in UAM usage. Furthermore, Rajendran et al. (2021) utilized machine learning algorithms and confirmed the critical impact of weather-related features, such as temperature and rain on UAM demand.

Few studies (Byun, 2021; Cho and Kim, 2022) have analyzed the demand for UAM in South Korea while considering preferences of potential users. They provided an understanding regarding the impact of travel time, travel cost, and the individual characteristics of potential users on the UAM selection. However, in analyzing the modal split, Byun (2021) only considered buses, subways, taxis, and UAM, and excluded private cars, which are one of the primary means of commute. Additionally, the analysis was carried out in a single operation scenario – intra-city trip. In contrast, Cho and Kim (2022) estimated the transit segment volume for various possible routes in the SMA, but failed to find the differences in the determinants of UAM selection in each case. It is crucial to analyze the factors that affect the demand for UAM in different operation scenarios, considering various means of transportation that are actually being used.

Therefore, the present study focused on addressing the following research questions: First, considering the existing modes of transportation in three scenarios (short-distance travel within the city, long-distance travel within the city, and intercity travel), what is the demand (modal share) for UAM? Second, considering public acceptance and preference, how does the demand for UAM vary based on its operational characteristics, such as time and cost, as well as the socio-demographic characteristics of potential users?

The estimation of demand for UAM is closely related to determining when, where, and to what extent UAM should be supplied. For instance, the location and number of ground infrastructure, such as vertiports, should be determined based on demand. The present study can contribute to establish plans for the introduction and operation of UAM that can respond to future demand by investigating the conditions under which the demand occurs.

3. Method

3.1. Case context

In South Korea, administrative divisions have three hierarchies. At the high-level, the entire territory of South Korea is divided into metropolitan city and province (Fig. 1). At the middle-level, metropolitan cities and provinces are divided into Si, Gun, and Gu (Fig. 2), which are same as city, county, and district in the United States. The Si, Gun, and Gu are divided into Eup, Myeon, and Dong as low-level administrative divisions (Fig. 3). The Eup, Myeon, and Dong correspond to town, township, and neighborhood.

South Korea has eight metropolitan cities (Seoul Special City, Incheon Metropolitan City, Busan Metropolitan City, Daegu Metropolitan City, Gwangju Metropolitan City, Daejeon Metropolitan City, Ulsan Metropolitan City, and Sejong Special Self–governing City) and nine provinces (Gyeonggi, Gangwon, Chungcheongnam, Chungcheongbuk, Jeollanam, Jeollabuk, Gyeongsangnam, Gyeongsangbuk, and Jeju Special Self–governing Province) as high-level administrative divisions. Among the high-level administrative divisions, we selected the SMA as the spatial scope of this study because this area would potentially have

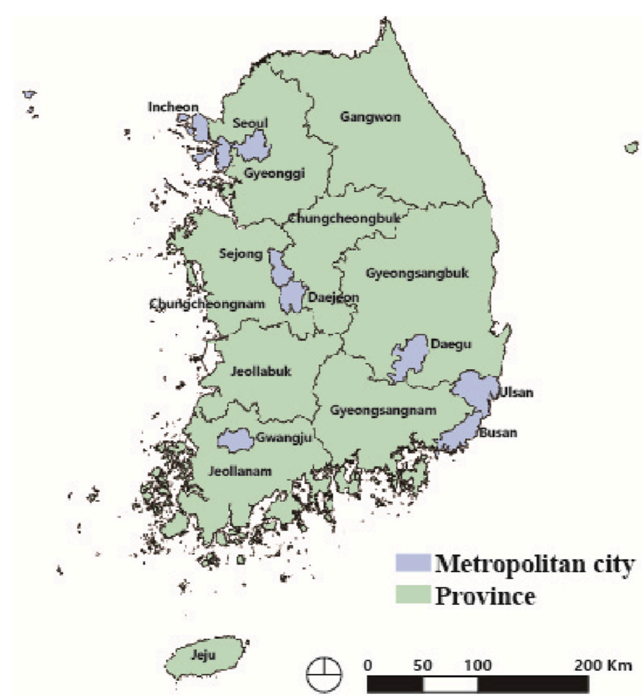

Fig. 1. High-level administrative divisions.

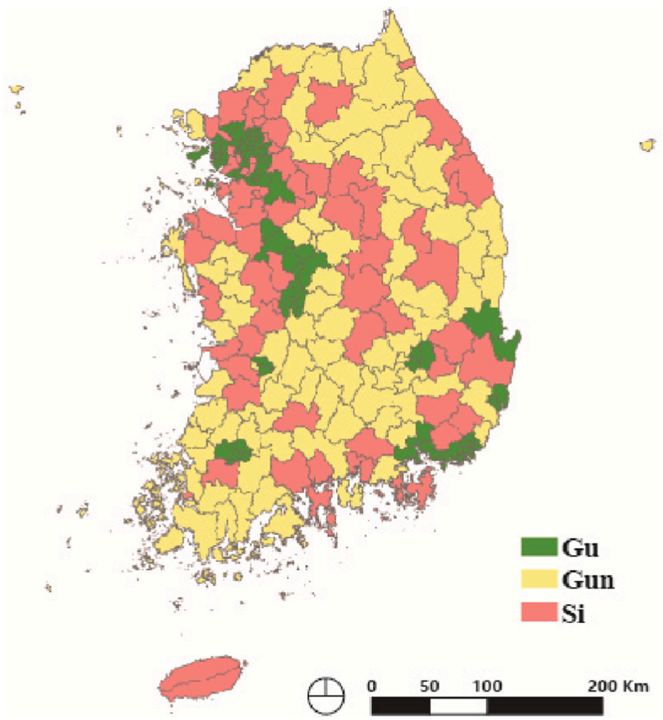

Fig. 2. Middle-level administrative divisions.

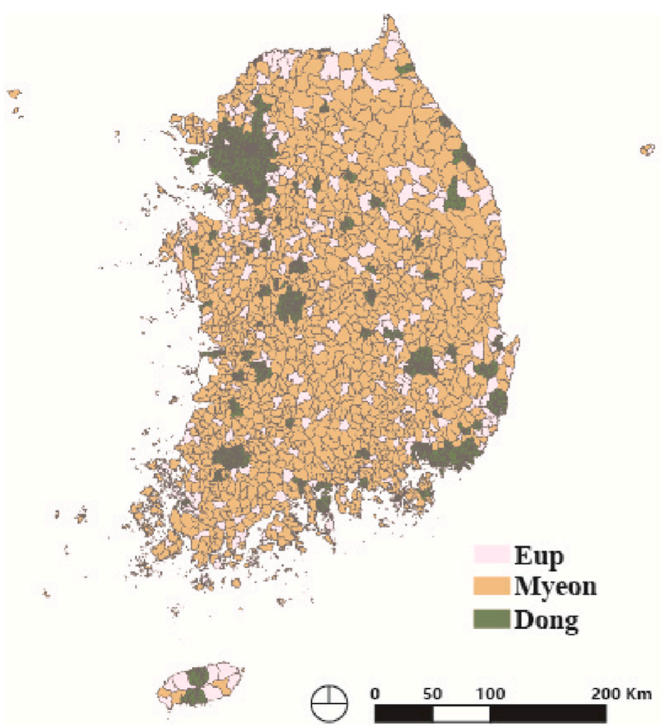

Fig. 3. Low-level administrative divisions.

the highest UAM usage in South Korea. As seen in Fig. 4, SMA includes Seoul Special City, the capital city of South Korea, and Gyeonggi Province and Incheon Metropolitan City, which are geographically adjacent to Seoul Special City. Table 1 summarizes the characteristics of the population, employees, and commuting traffic of each high-level administrative division. In 2019, the SMA had a population of 26,694,252, which accounts for approximately 50.24% of the total population of South Korea, and the number of employees was 6,780,523, accounting for approximately 54.08% of the total number of employees in South Korea. Additionally, these three administrative divisions are the top three areas with the highest commuting traffic.

Furthermore, Seoul Special City, Gyeonggi Province, and Incheon Metropolitan City are closely linked functionally. Seoul Special City, as shown in Fig. 4, has three central business districts (CBD): Jongno, Yeouido, and Gangnam. Jongno has served as the center of Seoul since the Joseon Dynasty (1392–1897) and is home to the presidential office, the Bank of Korea, newspaper offices, and other large companies. The major financial institutions are located in Yeouido, a financial center. Gangnam is a business center in which many companies are located. In Gyeonggi Province and Incheon Metropolitan City, there are five first-generation new towns[2] developed in the 1990s and 10 s-generation new towns[3] that have been developed since the 2000s, as shown in Fig. 4. First-generation new towns and second-generation new towns are located 20–25 km and 30–40 km away from Seoul Special City, functioning as bed-towns. The spatial structure with many jobs in Seoul's CBD and bed-towns in the suburbs causes a lot of long-distance commuting. This implies that the demand for UAM is highly likely to occur in the SMA.

Subsequently, at the middle-level administrative divisions, a pair of regions was selected for each of the three UAM operation scenarios. In this study, the short-distance intra-city trip was defined as the travel between the adjacent Gu and Gu in Seoul Special City. The long-distance intra-city trip was defined as the travel between the three CBDs in Seoul Special City. The inter-city trip was defined as the travel from Gu (or Gun) in Gyeonggi Province and Incheon Metropolitan City to Gu in Seoul Special City. For all the possible cases in each of the three scenarios, the current traffic volume was investigated from the origin-destination (OD) data of the Korea Transport Database. Then, in each scenario, the case with the highest traffic volume was selected as the final study area. In the short-distance intra-city trip scenario, Songpa-Gu and Gangnam-Gu in Seoul Special City were selected, as shown in Fig. 5. In the long-distance intra-city trip scenario, Yeongdeungpo-Gu and Gangnam-Gu in Seoul Special City were selected, as shown Fig. 6. Finally, Bundang-Gu in Gyeonggi Province and Gangnam-Gu in Seoul Special City were selected as study area for the inter-city trip scenario, as shown in Fig. 7.

Next, clearly defined origins and destinations of UAM were determined to measure the UAM flight distance in each of the three scenarios. In this study, we assumed subway stations as the take-off and landing locations of UAM. This enables the enhancement of accessibility to UAM and the network with existing ground public transportation in built-up areas. The total length of the subway system in SMA, which is used by approximately 3.2 billion passengers annually, is 1218.4 km. These indicate that subway stations function as major transportation nodes and may be suitable places for UAM ground infrastructure.

We used public transportation survey data and selected specific subway stations that have the largest number of passengers during rush hour (7–9 am and 6–8 pm). Therefore, Jamsil station and Gangnam station on Subway Line 2 were selected for Scenario 1; Yeouido station and Sinnonhyeon station on Subway Line 9 were selected for Scenario 2; and Yatap station on Subway Bundang Line and Seolleung station on Subway Line 2 were selected for Scenario 3. Then, based on these results, travel distance of UAM was measured in each scenario as 6.6 km in Scenario 1, 9.1 km in Scenario 2, and 12.5 km in Scenario 3. Although 6.6 km may be a short distance for UAM flights, there is a high demand for short-distance transportation within the compact urban structure of Seoul. Therefore, to effectively alleviate ground traffic congestion, even

[2] Bundang New Town, Ilsan New Town, Sanbon New Town, Jungdong New Town, and Pyungchon New Town.

[3] Pangyo New Town, Dongtan 1 New Town, Dongtan 2 New Town, Hangang New Town, Unjeong New Town, Gwanggyo New Town, Yangju New Town, Wirye Now Town, Goduk New Town, and Geomdan New Town.

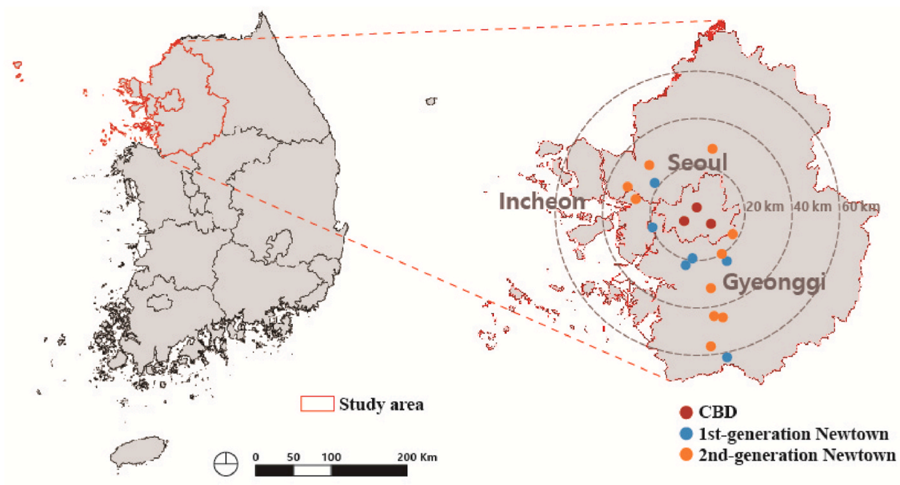

Fig. 4. Study area; Seoul metropolitan area.

Table 1
Characteristics of population, employees and commuting traffic in 2019.

High-level administrative divisions		Population		Employees		Commuting traffic	
		N	%	N	%	N/day	%
Seoul Metropolitan Area	Seoul	10,010,983	18.84	3,464,411	27.63	791,666	13.42
	Gyeonggi	13,653,984	25.70	2,747,556	21.91	2,898,381	49.13
	Incheon	3,029,285	5.70	568,556	4.53	403,948	6.85
	Sum	26,694,252	50.24	6,780,523	54.07	4,093,995	69.40
Others	Busan	3,466,563	6.52	842,161	6.72	144,937	2.46
	Daegu	2,468,222	4.65	549,232	4.38	158,073	2.68
	Gwangju	1,480,293	2.79	364,864	2.91	89,931	1.52
	Daejeon	1,493,979	2.81	366,278	2.92	69,449	1.18
	Ulsan	1,168,469	2.20	233,611	1.86	34,974	0.59
	Sejong	346,275	0.65	54,095	0.43	34,894	0.59
	Gangwon	1,560,571	2.94	384,868	3.07	107,352	1.82
	Chungbuk	1,640,721	3.09	341,993	2.73	98,701	1.67
	Chungnam	2,194,384	4.13	441,873	3.52	163,938	2.78
	Jeonbuk	1,851,991	3.49	387,857	3.09	154,044	2.61
	Jeonnam	1,903,383	3.58	389,087	3.10	187,955	3.19
	Gyeongbuk	2,723,955	5.13	529,036	4.22	199,777	3.39
	Gyeongnam	3,438,676	6.47	681,153	5.43	329,502	5.59
	Jeju	696,657	1.31	191,116	1.52	31,883	0.54
Total		53,128,391	100.00	12,537,747	100.00	5,899,405	100.00

short distances should be considered as main routes for UAM.

3.2. Stated preference survey

This study adopted the SP method to survey the willingness of potential users to use UAM. The SP method has been defined as "a family of techniques that use individual respondent's statements about their preferences in a set of transport options to estimate utility functions (Kroes and Sheldon, 1988)." These techniques were developed in the early 1970s for use in marketing; subsequently, from the 1980s, it has been used extensively in transportation-related studies. The SP method is a useful tool for identification of the potential demand for future transportation that does not yet exist. Using this method, the individual preferences for a specific alternative in a hypothetical situation can be investigated.

3.2.1. Setting of the alternatives

In the SP survey, a number of choice sets were given to the users. For each set of choices, respondents were asked to express their preference for a particular alternative in one of three ways: to list each alternative in the order of preference, to express the degree of preference using a scale, and to choose one of the proposed alternatives. Every choice set consisted of several alternatives, including a target alternative. In this study, we selected buses, subways, taxis, and private cars as alternatives to UAM.

3.2.2. Setting of the attributes

Respondents had to make a choice from the many alternatives provided to them. The characteristics or attributes of these alternatives help respondents to make a decision. Typically, four to six attributes are considered in the SP survey (Kim and Jo, 2006). The respondents have difficulty in decision-making if the number of attributes is extremely large or small.

Typically, time and cost are the most important and common requirements for passengers in choosing transportation Accordingly, many SP surveys on the means of transportation have included travel time and travel cost as the main attributes (Fu, 2018). In addition, some studies concerning UAM have stated that safety and privacy are psychological barriers to UAM. In particular, it was found that more than half of the respondents tended not to board autonomous vehicles (Castle et al., 2017). In the present study, six attributes were selected: access time,

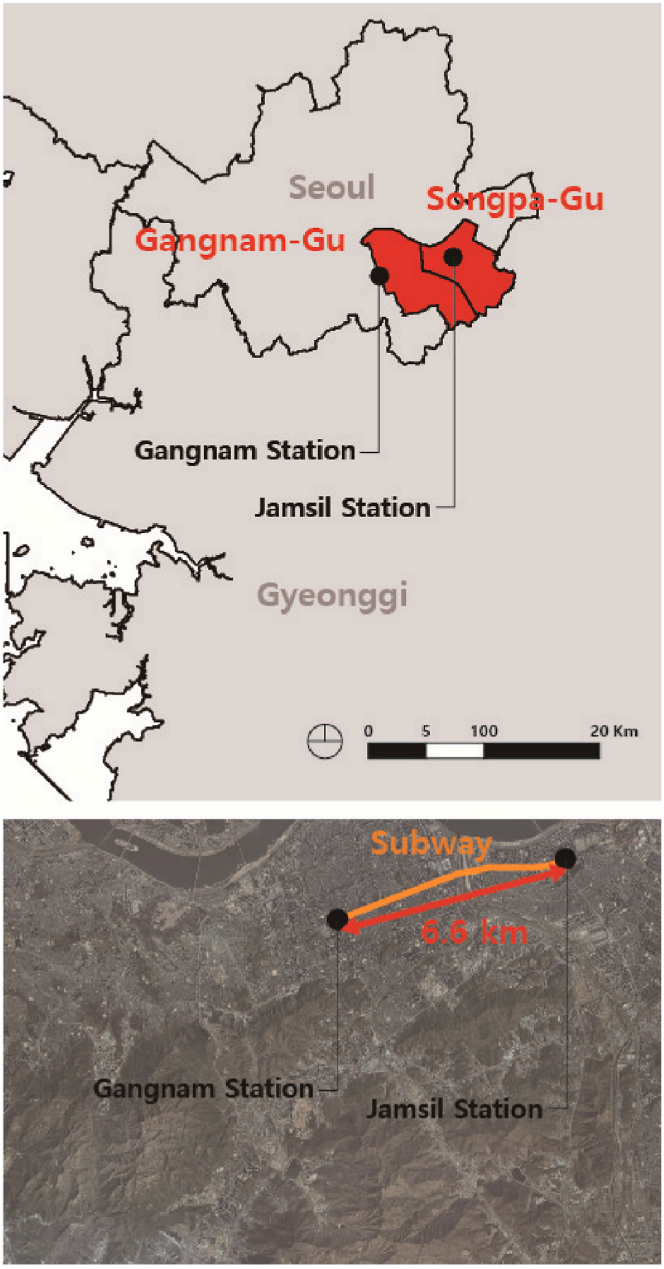

Fig. 5. Gu-Gun level study area (Scenario 1).

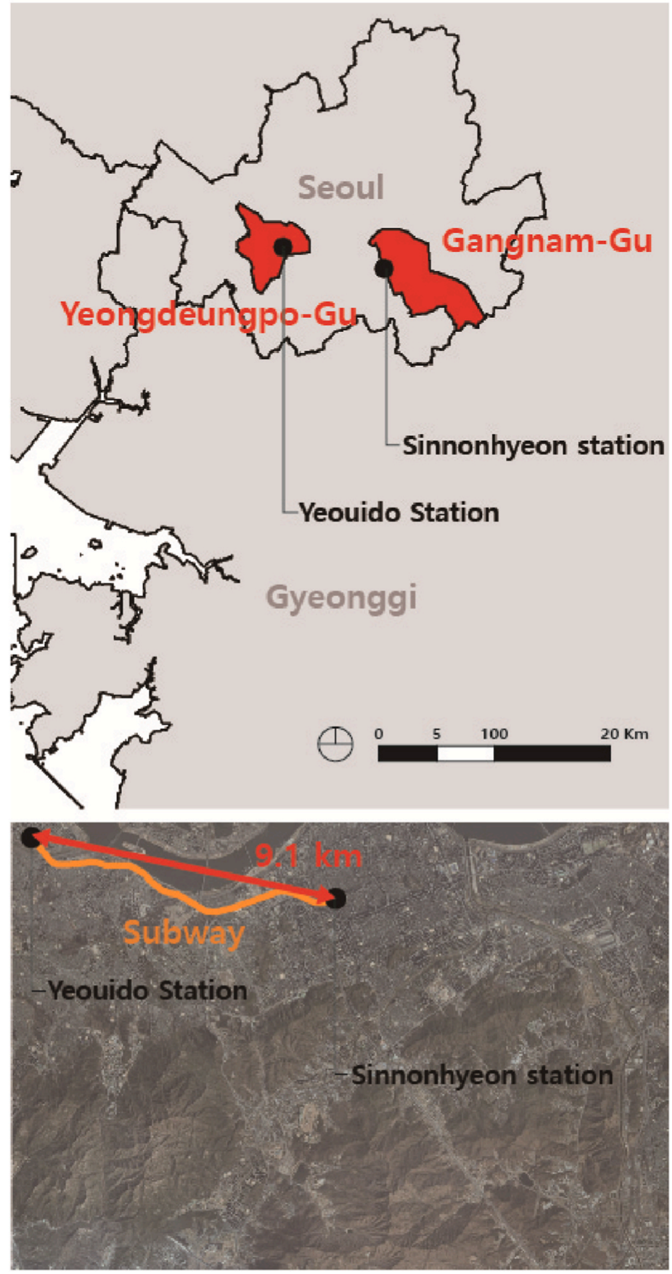

Fig. 6. Gu-Gun level study area (Scenario 2).

waiting time, boarding time[4], cost, autonomous mode, and the presence of other passengers, as the major service characteristics.

3.2.3. Setting of the levels

Table 2 summarizes the alternatives, attributes, and attributes levels for each of the scenarios. The values of each attribute (levels) were set based on the current situation. The specific value for each level was determined as follows.

3.2.3.1. Attribute levels in scenario 1. First, in the case of subways, the levels of each attribute were set as follows: The access time is the time taken to walk to the subway station. Assuming that the distance from home or office to the subway station is 300 m, 500 m, and 900 m, the access time was set to 8, 14, and 24 min. Based on the existing schedule for actual subway line, the waiting time for the subway was set to 3 min. To set the boarding time and cost, real-time traffic data provided by the KAKAO map service (Fig. 8) were used. It was revealed that the boarding time and cost for subway in Scenario 1 was 12 min and 1250 won. In this case, only the shortest subway route with minimum transfer was considered. In addition, the current operational characteristics of subway, such as manual driving and boarding of multiple passengers, were considered.

Second, in the case of buses, the access time was set to 8, 14, and 24 min, similar to subways, considering the walking distance of 300 m, 500 m, and 900 m between bus stop and home (or office). The waiting time for bus was set to 7 min, which is the time for the most used bus line in Seoul on weekdays, as per the Public Transportation Status Survey Report (Jung et al., 2019). Considering two bus routes surveyed in real-time traffic data, the boarding time was set to 27 and 47 min, and

[4] In this study, boarding time comprises the time taken for passengers to board the vehicle, time spent within the vehicle during its journey, and time required for the passengers to get off the vehicle.

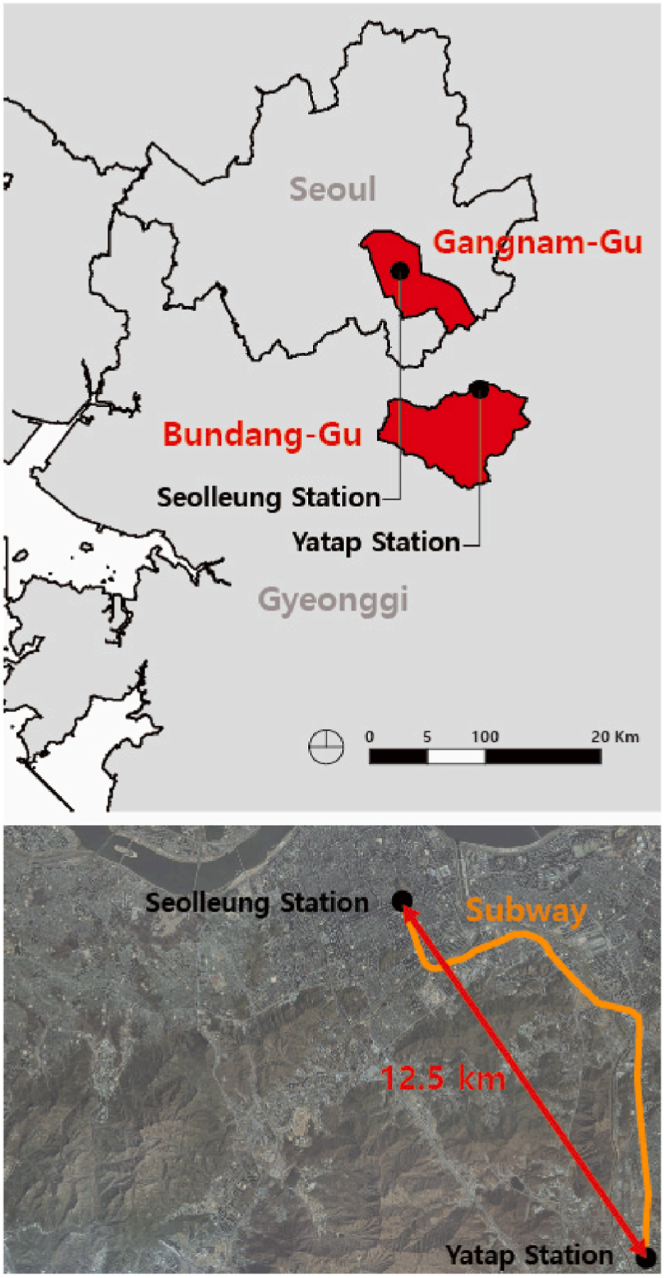

Fig. 7. Gu-Gun level study area (Scenario 3).

the cost was set to 2800 and 1200 won. Buses were assumed to be operated by drivers and accommodate multiple passengers.

Third, in the case of taxi, the access time was set to 4 min because it is a door-to-door transportation. We assumed that the time spent on walking from home to taxi and from taxi to office was 2 min. The waiting time was set to be 0 min. This is because, at present, in South Korea, it is possible to get into a taxi at a desired location without waiting by using a smartphone application. We set the boarding time and cost to 37 min and 12,300 won using real-time traffic data from the KAKAO map service. Finally, by considering the current operational characteristics, we assumed that the taxi had no other passengers except the driver and the respondent.

Fourth, in the case of private cars, the access time was set to 4 min considering 2 min of walking time from home to parking lot or from parking lot to office. The waiting time was set to be 0 min because, unlike the subway and buses that operate on a regular schedule, private car is immediately available. The boarding time and cost were set to 37 min and 1200 won based on real-time traffic data from the KAKAO map service. It was assumed that the respondent drives the vehicle alone without any passengers.

Table 2
Summary of alternatives, attributes, and attributes levels.

Attributes		Alternative				
		Subway	Bus	Taxi	Private car	UAM
Scenario 1 (Short-distance intra-city trip)	Access time (min)	8, 14, 24	8, 14, 24	4	4	4, 14, 24
	Waiting time (min)	3	7	0	0	0, 3, 7
	Boarding time (min)	12	27, 47	37	37	10.15, 20
	Cost (1000 won)	1.25	2.8, 1.2	12.3	1.2	3.3, 9.9, 19.8
	Autonomous mode	No	No	No	No	Yes, No
	Other passengers	Yes	Yes	No	No	Yes, No
Scenario 2 (Long-distance intra-city trip)	Access time (min)	8, 14, 24	8, 14, 24	4	4	4, 14, 24
	Waiting time (min)	8	7	0	0	0, 3, 7
	Boarding time (min)	14, 26	44, 52	43	43	11, 18, 26
	Cost (1000 won)	1.35, 1.35	2.8, 1.2	15.5	1.9	4.6, 13.7, 27.3
	Autonomous mode	No	No	No	No	Yes, No
	Other passengers	Yes	Yes	No	No	Yes, No
Scenario 3 (inter-city trip)	Access time (min)	8, 14, 24	8, 14, 24	4	4	4, 14, 24
	Waiting time (min)	5	7	0	0	0, 3, 7
	Boarding time (min)	26	35, 58	59	59	12, 22, 32
	Cost (1000 won)	1.45	2.8, 2.3	24.0	2.4	6.3, 18.8, 37.5
	Autonomous mode	No	No	No	No	Yes, No
	Other passengers	Yes	Yes	No	No	Yes, No

Fifth, in the case of UAM, we first assumed the characteristics of UAM aircraft, as shown in Table 3. These criteria were first presented by Uber (2016) and have been continually used in studies that conducted simulations for UAM operation (Rothfeld et al., 2018, 2019; Pukhova et al., 2019; Fu et al., 2020; Al Haddad et al., 2020). According to NASA (2018), air metro moves along predetermined or scheduled routes similar to buses and subways, and air taxis are operated on-demand without scheduled or planned routes similar to taxis and private cars. We chose both modes of operations in our survey.

Based on these assumptions, the access time in UAM was set to 4 min for the air taxi mode, aligning with that of taxis or private cars, and 14 and 24 min for the air metro mode, aligning with that of subways or buses. Waiting time was set to 0 min for air taxi mode, and 3 and 7 min for air metro mode. The boarding time of UAM includes pre-flight process time, take-off time, in-vehicle travel time, landing time, and post-flight process time. Referring to previous studies (Al Haddad et al., 2020; Mayakonda et al., 2020), the pre-flight process time required for safety inspections before take-off was set to 3 min. The take-off time was set to 1 min by applying a take-off speed of 10 m/s and a flight altitude of 600 m. The in-vehicle travel time was calculated by applying the linear distance between the origin and destination to a flight speed of 150

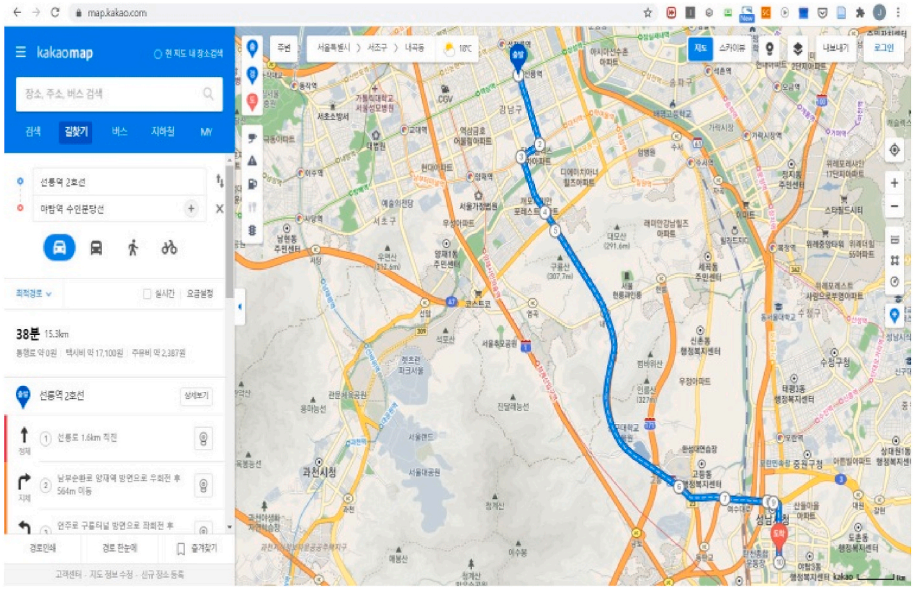

Fig. 8. KAKAO map service.

Table 3
Characteristics of UAM aircraft.

Cruise speed [km/h]	150
Cruise altitude [m]	600
Vertical take-off and landing speed [m/s]	10
Vehicle passenger capacity [# of seats]	4
Operation mode	Air metro, air taxi

km/h. Based on this, the in-vehicle travel time was set to 3 min in Scenario 1. The landing time was set to 1 min, similar to the take-off time. The post-flight process time was set to 2 min, referring to Mayakonda et al. (2020). In addition, we assumed that, if the UAM has stopovers, there would be additional 5 min corresponding to the landing time, pre-flight process time, and take-off time per stopover. Taking all of these into consideration, the total boarding time was set to 10 min for an air taxi mode with no stopover. For the air metro mode with stopovers, we assumed the presence of one and two stopovers, thus setting the total boarding time to 15 and 20 min, respectively. According to MOLIT (2020), the initial fare for UAM is expected to be \$3/km to \$4/km (approximately 3000 won per kilometer). Furthermore, if autonomous flight is adopted, it is expected to decrease to \$0.6/km (approximately 500 won per kilometers). Therefore, in this study, the fare per km was taken as 500 won, 1500 won, and 3000 won. We set the cost for UAM in scenario 1 to 3,300, 9,900, and 19,800 won by applying the fare per km to the straight distance of 6.6 km between the origin and destination. Finally, both manual and autonomous flights, with or without extra passengers, were considered.

3.2.3.2. Attribute levels in scenario 2. In Scenario 2, first, the access time for the subway was set to 8, 14, and 24 min, considering the walking distance to the subway station, which is the same as in Scenario 1. Based on the actual subway schedule data, the waiting time was set to 8 min. In this case, the subway operates with two types of trains: (1) express trains and (2) local trains. Considering these two types of trains, we set the boarding time to 14 min for express trains, and 26 min for local trains. Cost was set as 1350 won based on the actual fare. The levels for autonomous mode and other passengers remained the same as in Scenario 1.

Second, in the case of buses, the boarding time was set to 44 and 52 min, and the cost was set to 2800 and 1200 won considering the actual data. The values for access time, waiting time, autonomous mode, and other passengers were set to the same values as those in Scenario 1.

Third, in the case of taxis, the levels of the remaining four variables, except for boarding time and cost, were set to the same values as in Scenario 1. The boarding time and cost were set to 43 min, and 15,500 won using KAKAO map service.

Fourth, for private car, the boarding time and cost were set to actual values obtained from KAKAO map service, specifically 43 min and 1900 won. The values of the remaining variables were kept the same as in Scenario 1.

Fifth, the access time for UAM was set to 4, 14, and 24 min, while the waiting time was set to 0, 3, and 7 min, which were the same values as those defined in Scenario 1. The minimum boarding time for UAM was set to 11 min, which included 3 min for pre-flight processes, 1 min for take-off, 1 min for landing, 2 min for post-flight processes, and 4 min for in-vehicle travel time (representing the time required to fly 9.1 km at a speed of 150 km/h). Additionally, we assumed two situations with two and three stopovers, respectively, and provided boarding time of 18 min and 26 min for each case. In Scenario 2, both manual and autonomous operations of UAM were considered, similar to Scenario 1. Furthermore, we considered both the situations of the respondent traveling alone and traveling with others in the UAM.

3.2.3.3. Attribute levels in scenario 3. In Scenario 3, the levels for each variable were set using the same approach as in Scenario 2. In the case of subways, the access time was set to 8, 14, and 24 min, waiting time was set to 5 min, boarding time was set to 26 min, and cost was set to 1450 won. In the case of buses, the access time was set to 8, 14, and 24 min, waiting time was set to 7 min, boarding time was set to 35 and 58 min, and cost was set to 2800 and 2300 won. For both taxis and private cars, access time was set to 4 min, waiting time was set to 0 min, and boarding time was set to 59 min. The cost of taxi and UAM were set to 24,000 and 2400 won based on the KAKAO map service. The levels for access time, waiting time, autonomous mode, and other passengers in UAM were set to the same values across all three scenarios. In Scenario 3, we assumed that air metro mode would have two and four stopovers. From this, we set boarding time to 12 min for air taxi mode, and 22 and 32 min for air metro mode. Considering a distance of 12.5 km, the cost was set to 6,300, 18,800, and 37,500 won.

3.2.4. Questionnaire design

After the alternatives, attributes, and levels were determined, it was necessary to identify the possible choice situations based on the combination of specific levels of each attribute from all alternatives. Factorial design is a method that can drastically reduce the number of required experiments by limiting the levels of attributes when collecting the data to predict the relationships between attributes; the full factorial design considers all possible situations and the fractional factorial design selects only some situations. The fractional factorial design can be used when the number of experiments in the full factorial design is extremely large (Kroes and Sheldon, 1988). This study derived a total of 27 SP questions in each scenario by applying a fractional factorial design based on the orthogonal table by Kocur et al. (1982).

In addition to SP questions, we surveyed the respondents' sociodemographic characteristics. These individual characteristics include gender, age, educational background, job, income, the presence of vehicles available, main transportation mode, prior knowledge of UAM, time and cost spent in in commuting.

3.2.5. Data collection

We conducted a survey, from 17 to 23 July 2021, on people in their 20–60s, living in SMA. A professional survey company conducted an online survey after providing sufficient explanation about UAM. Several studies have identified the minimum number of samples necessary for an SP survey. Bradley and Kroes (1990) noted that 75–100 samples were needed for each group. Suzuki et al. (2002) confirmed that the minimum sample size for estimating models in an SP experiment was approximately 100 from the test using 234 samples of 39 respondents. Additionally, the authors stated that, if the survey is well-designed, a sample size of 100–300 is sufficient for the model estimation. In the present study, 300 people were surveyed, among which, 100 were selected for each of the three scenarios. Furthermore, the valid samples were selected; 2403 samples of 89 respondents for Scenario 1, 2430 samples of 90 respondents for Scenario 2, and 2700 samples of 100 respondents for Scenario 3 were analyzed.

3.3. Statistical model

Discrete choice model is a regression model to predict the effects of explanatory variables on the choice among the two or more alternatives. It explains why a particular choice is made based on Random Utility Theory. According to the theory, most people choose an alternative that provides the maximum utility (Lee and No, 2015). Here, the utility refers to the attractiveness of the alternative and is determined by the attributes describing the alternative, such as boarding time and fare in the case of transportation.

The utility of alternative j can be mathematically defined as Eq. (1): $U_j = V_j + \varepsilon_j$, where U_j is the latent utility, V_j is observable deterministic utility, and ε_j is unobservable random utility. Deterministic utility is generally expressed as a linear regression model, such as Eq. (2): $V_j = \alpha_j + BX_j$, where X_j is a vector of alternative-specific variables that explains the characteristics of alternative j, and B is a vector of preference parameters.

$$U_j = V_j + \varepsilon_j, \tag{Eq. 1}$$

$$V_j = \alpha_j + BX_j. \tag{Eq. 2}$$

Conditional logistic regression model is one of the most popular discrete choice models. In this model, the probability of selecting alternative j among alternatives n is calculated, as shown in Eq. (3). From this, the log-odds of the alternative j are expressed, as shown in Eq. (4) when the alternative J is a reference group. The parameters of B estimated in a conditional logistic regression model indicate the importance of attributes for the respondents in the decision-making process of selecting an alternative and have the same value irrespective of the alternative.

$$\mathrm{P}(Y = j) = e^{V_j} \Big/ \sum_{k=1}^{n} e^{V_k}, \tag{Eq. 3}$$

$$\mathrm{Ln}(P(Y = j) / P(Y = J)) = V_j - V_J = (\alpha_j - \alpha_J) + B(X_j - X_J). \tag{Eq. 4}$$

In this study, McFadden's choice model (McFadden, 1974), the specific type of the conditional logistic regression model, was used to identify the factors that determine the intention to use UAM. This model allows alternative-specific variables, such as time and cost, and case-specific variables that include gender and age of respondents for explanatory variables. For example, let us assume that there are p alternative-specific variables, and q case-specific variables. In this case, the deterministic utility that individual i can get from the alternative j is defined, as shown in Eq. (5). Here, B is a $1 \times p$ vector of regression coefficients for alternative-specific variables and X_j indicates $p \times 1$ data vector for the alternative j. Γ_j indicates a $1 \times q$ vector of regression coefficients for case-specific variables and Z indicates $q \times 1$ data vector for individual i.

$$V_j = \alpha_j + BX_j + \Gamma_j Z = \alpha_j + \sum_{l=1}^{p} \beta_l x_{jl} + \sum_{m=1}^{q} \gamma_{jm} z_m. \tag{Eq. 5}$$

Stata (version17) was used to estimate the parameters. The SP data used in this study was panel data, wherein a certain number of analysis samples were collected from one respondent. Stata's *cmclogit* command enables the analysis of panel data.

4. Results

4.1. Descriptive statistics of the respondents

Table 4 summarizes the descriptive statistics of the respondents' individual characteristics. In every scenario, the number of respondents under each sex and age group did not differ. More than 60% of the respondents were professionals, such as doctors, lawyers, accountants, and engineers, or had a white-collar job. The proportion of respondents with a monthly income of 3 million won or more was approximately 70%. Approximately 70–80% of the respondents owned personal vehicles. For commuting, subways/trains were the most frequently used modes, followed by buses and private cars. More than 50% of the respondents did not have prior knowledge of UAM.

4.2. Factors influencing the intention to use UAM

Tables 5–7 show the analysis results of the factors that determine the intention of respondents to use UAM for commuting in scenarios of short-distance intra-city trip, long-distance intra-city trip, and, inter-city trip respectively. In the three models, the McFadden R-square values were 0.3087, 0.2421, and 0.2370.

The explanatory variables that have a statistically significant effect on the dependent variable with a 95% confidence level are as follows. As revealed in earlier studies (Al Haddad et al., 2020; Balac et al., 2019; Byun, 2021; Cho and Kim, 2022; Pukhova et al., 2019; Rothfeld et al., 2018), cost negatively affects the UAM preference in all scenarios. In contrast to the existing studies that argued the negative effect of the travel time on the UAM selection (Al Haddad et al., 2020; Byun, 2021; Cho and Kim, 2022), the relationship between the travel time and the intention of using UAM in the three scenarios was different depending on whether the travel time was required for access, waiting, or boarding. The travel time spent to access the UAM negatively affects the use of the UAM, regardless of the flight distance. However, waiting time has a negative effect only in inter-city trips ($\beta = -0.0322$). This shows that the longer the distance to the destination, the more critical is the passenger's reaction to the waiting time. Previous studies have identified that the process time, time for vertical takeoff and landing and the time for cruise negatively affected UAM selection (Balac et al., 2019; Pukhova et al.,

Table 4
Summary of respondents' characteristics.

Variables		Scenario 1 (Short-distance intra-city trip)		Scenario 2 (Long-distance intra-city trip)		Scenario 3 (Inter-city trip)		South Korea	
		N	%	N	%	N	%	N	%
	Total	89	100.00	90	100.00	100	100.00	51,259,150	100.00
Gender	Male	43	48.31	44	48.89	50	50.00	25,540,042	49.83
	Female	46	51.69	46	51.11	50	50.00	25,719,108	50.17
Age	20s	16	17.98	20	22.22	20	20.00	6,516,721	12.71
	30s	18	20.22	16	17.78	20	20.00	6,635,875	12.95
	40s	17	19.10	19	21.11	20	20.00	8,060,737	15.73
	50s	19	21.35	20	22.22	20	20.00	8,548,547	16.68
	≥60s	19	21.35	15	16.67	20	20.00	13,153,956	25.66
Educational background	High school	12	13.48	19	21.11	11	11.00	N/A	
	University	70	78.65	61	67.78	80	80.00		
	Master's degree	3	3.37	9	10.00	7	7.00		
	Doctoral degree	4	4.49	1	1.11	2	2.00		
Job	Professional workers	5	5.62	6	6.67	10	10.00	N/A	
	Office	67	75.28	53	58.89	64	64.00		
	Sales service	6	6.74	14	15.56	9	9.00		
	Labor	5	5.62	6	6.67	9	9.00		
	primary industry	0	0.00	0	0.00	0	0.00		
	Private business	0	0.00	0	0.00	0	0.00		
	Student	6	6.74	11	12.22	8	8.00		
	Unemployed	0	0.00	0	0.00	0	0.00		
	Others	0	0.00	0	0.00	0	0.00		
Income	<1,000,000	1	1.12	2	2.22	2	2.00	N/A	
	1,000,000 \-2,000,000\	6	6.74	6	6.67	6	6.00		
	2,000,000 \-3,000,000\	17	19.10	15	16.67	19	19.00		
	3,000,000 \-5,000,000	36	40.45	35	38.89	31	31.00		
	≥5,000,000\	29	32.58	32	35.56	42	42.00		
The presence of available vehicles	Yes	67	75.28	73	81.11	82	82.00	N/A	
	No	22	24.72	17	18.89	18	18.00		
Main transportation mode	Subway	39	43.82	35	38.89	43	43.00	N/A	
	Bus	19	21.35	29	32.22	22	22.00		
	Taxi	5	5.62	3	3.33	1	1.00		
	Private car	21	23.60	20	22.22	28	28.00		
	Bicycle	1	1.12	2	2.22	1	1.00		
	Others	4	4.49	1	1.11	5	5.00		
Knowledge of UAM	Yes	34	38.20	42	46.67	30	30.00	N/A	
	No	55	61.80	48	53.33	70	70.00		
Variables	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation			
Time for commuting [min]	41.04	22.55	48.29	36.89	45.76	23.50		N/A	
Cost for commuting [1000 won]	2.11	1.88	2.57	2.19	2.54	2.11			

2019; Rothfeld et al., 2018). In contrast, in the present study, the negative effect of the boarding time on UAM selection was found to be statistically significant only in long-distance intra-city trip (β = −0.0650) and inter-city trip (β = −0.0311). The boarding time did not significantly affect the UAM selection in short-distance intra-city trips. This result shows that a 1 min difference is insignificant in the trips that take a short time to move and does not affect the transportation choices. The UAM is expected to be used more frequently when driven autonomously compared to that when driven by a driver. The presence of other passengers did not have a statistically significant effect on the UAM selection.

When the reference group is set to UAM, the results of analyzing the effect of individual characteristics on buses, subways, taxis, and private cars selection are as follows. As for the effect of gender on UAM selection, different results have been presented in existing studies. Al Haddad et al. (2020) and Byun (2021) found that men showed more interest in UAM adoption than women; however, Cho and Kim (2022) found that gender did not affect the UAM selection. In our study, gender does not have a statistically significant effect on UAM selection, except for the fact that the probability of choosing subways instead of UAM is higher in female than male in long-distance intra-city trip.

Byun (2021) and Cho and Kim (2022) reported that age did not affect UAM preference. On the other hand, this study found that older adults aged 65 years or older are more likely to choose private cars over UAM than the others in inter-city trip (β = 1.6128). However, they are less likely to choose private cars over UAM compared to the others in long-distance intra-city trip (β = −1.0374) and short-distance intra-city trip (β = −1.8060). Furthermore, in short-distance intra-city trip, older adults have a higher tendency to choose UAM over buses (β = −4.7469), subways (β = −1.1398), and taxis (β = −17.4908) than non-seniors. These results revealed that the older adults tend to prefer UAM as an alternative means in short trips, however, exhibit hesitation when selecting UAM in long trips.

The probability of choosing buses and taxis instead of UAM is lower in those with high educational background than those with low educational background in inter-city trip. However, in other cases, the effect of education level on the UAM selection is not statistically significant, which is the same as the previous study result (Byun, 2021). It was found that whether a respondent is student or not does not significantly affect the probability of choosing buses, subways, and private cars over UAM in all scenarios. However, in terms of the probability of choosing taxis, similar to the older adults, students tend to choose taxis over UAM for inter-city trip (β = 3.3597) but choose UAM over taxis for long-distance intra-city trip (β = −12.5141).

Table 5
Factors influencing intention to use UAM (short-distance intra-city trip).

Variables		Alternatives			
		Bus	Subway	Taxi	Private Car
		Coefficient			
Alternative-specific variables	Access time [min]	−0.0709*** (0.000)			
	Waiting time [(min]	−0.0407 (0.123)			
	Boarding time [min]	−0.0173 (0.178)			
	Cost [1000 won]	−0.1514*** (0.000)			
	Autonomous mode (1: Yes, 0: No)	0.3026** (0.029)			
	Other passengers (1: Yes, 0: No)	0.0528 (0.742)			
Case-specific variables	ASC	0.4624 (0.770)	2.4173*** (0.000)	1.7760 (0.412)	0.0682 (0.938)
	Gender (1: Female, 0: Male)	0.7453 (0.293)	0.1058 (0.772)	0.14134 (0.811)	0.2009 (0.683)
	Age (1: ≥60s, 0: Others)	−4.7469*** (0.000)	−1.1398** (0.026)	−17.4908*** (0.000)	−1.8060*** (0.001)
	Educational background (1: ≥University, 0: Others)	0.6020 (0.624)	−0.7845 (0.091)	−1.3510 (0.163)	0.0932 (0.901)
	Job (1: Student, 0: Others)	0.7894 (0.464)	−0.0554 (0.917)	−1.1054 (0.627)	1.0315 (0.281)
	Income (1: ≥5,000,000\, 0: Others)	−0.2478 (0.790)	0.6244 (0.110)	1.3831* (0.084)	1.2238** (0.010)
	The presence of available vehicles (1: Yes, 0: No)	0.1251 (0.891)	−0.3494 (0.328)	−0.1586 (0.897)	−0.0623 (0.924)
	Main transportation mode: Subway (1: Yes, 0: No)	−0.3759 (0.639)	0.4956 (0.238)	0.9009 (0.278)	−1.2624*** (0.006)
	Main transportation mode: Bus (1: Yes, 0: No)	0.8747 (0.189)	−0.7950* (0.067)	0.0313 (0.964)	−0.2495 (0.622)
	Main transportation mode: Taxi (1: Yes, 0: No)	−1.4629 (0.192)	−0.5002 (0.331)	−0.5985 (0.470)	0.2110 (0.747)
	Main transportation mode: Private Car (1: Yes, 0: No)	0.9214 (0.301)	0.1439 (0.811)	2.1198* (0.066)	2.7125*** (0.000)
	Cost for commuting [1000 won]	−0.0425 (0.832)	−0.2941** (0.014)	−0.4303* (0.085)	−0.2053* (0.070)
	Time for commuting [min]	−0.0455* (0.053)	0.0166** (0.045)	−0.0636** (0.018)	−0.0100 (0.479)
	Knowledge of UAM (1: Yes, 0: No)	−1.8711*** (0.000)	−1.6586*** (0.000)	−1.5129** (0.033)	−2.6243*** (0.000)
Model fit	Log-Likelihood	−2241.6284			
	McFadden R-square	0.3087			

*<0.1 **P < .05, ***P < .01.

Table 6
Factors influencing intention to use UAM (long-distance intra-city trip).

Variables		Alternatives			
		Bus	Subway	Taxi	Private Car
		Coefficient			
Alternative-specific variables	Access time [min]	−0.0574*** (0.000)			
	Waiting time [(min]	−0.0153 (0.358)			
	Boarding time [min]	−0.0650*** (0.000)			
	Cost [1000 won]	−0.0967*** (0.000)			
	Autonomous mode (1: Yes, 0: No)	0.1568 (0.101)			
	Other passengers (1: Yes, 0: No)	0.0954 (0.382)			
Case-specific variables	ASC	0.7758 (0.438)	0.6054 (0.418)	−0.2537 (0.865)	0.6150 (0.465)
	Gender (1: Female, 0: Male)	0.1198 (0.865)	0.8607** (0.033)	−0.5259 (0.550)	0.6045 (0.135)
	Age (1: ≥60s, 0: Others)	0.4020 (0.535)	−0.6694 (0.172)	−0.6309 (0.526)	−1.0374** (0.029)
	Educational background (1: ≥University, 0: Others)	0.0638 (0.910)	−0.1845 (0.652)	−0.2822 (0.822)	−0.7006* (0.069)
	Job (1: Student, 0: Others)	0.3807 (0.623)	0.7117 (0.156)	−12.5141*** (0.000)	0.5164 (0.386)
	Income (1: ≥5,000,000\, 0: Others)	1.4016* (0.052)	0.1058 (0.779)	−0.3633 (0.746)	−0.4565 (0.284)
	The presence of available vehicles (1: Yes, 0: No)	−2.6338** (0.015)	−0.3478 (0.415)	−1.6619 (0.300)	0.3121 (0.562)
	Main transportation mode: Subway (1: Yes, 0: No)	1.0341 (0.118)	0.0760 (0.853)	0.9261 (0.270)	−0.6759 (0.142)
	Main transportation mode: Bus (1: Yes, 0: No)	1.3665 (0.101)	−0.7943** (0.041)	0.0376 (0.960)	−1.4488*** (0.001)
	Main transportation mode: Taxi (1: Yes, 0: No)	1.1784 (0.395)	0.7088 (0.600)	1.2387 (0.252)	0.9695 (0.242)
	Main transportation mode: Private Car (1: Yes, 0: No)	1.7084* (0.073)	−0.5515 (0.195)	3.6061*** (0.001)	1.2580*** (0.008)
	Cost for commuting [1000 won]	−0.0604 (0.647)	0.0425 (0.650)	−0.1692 (0.547)	0.0883 (0.216)
	Time for commuting [min]	−.0457*** (0.004)	0.0033 (0.578)	−0.0314 (0.152)	−0.0003 (0.965)
	Knowledge of UAM (1: Yes, 0: No)	−1.3091 (0.110)	−0.0309 (0.937)	−1.6104* (0.074)	−0.2319 (0.595)
Model fit	Log-Likelihood	−2080.9765			
	McFadden R-square	0.2421			

*<0.1 **P < .05, ***P < .01.

Several studies have shown that the higher the income, the better is the UAM adoption (Al Haddad et al., 2020; Byun, 2021). However, Cho and Kim (2022) demonstrated that both low and high incomes negatively affected the UAM selection. In the present study, people with high income were more likely to choose UAM over buses and taxis for inter-city trips compared to those with low income; however, they were more likely to choose private cars over UAM for short-distance intra-city trips. As such, the impact of income was expected to vary depending on the trip distance and alternative transportation.

People with personal vehicles were more likely to use the UAM instead of the buses than those who don't have their own vehicles for long-distance intra-city trip (β = −2.6338). People who usually used the

Table 7
Factors influencing intention to use UAM (inter-city trip).

Variables		Alternatives			
		Bus	Subway	Taxi	Private Car
		Coefficient			
Alternative-specific variables	Access time [min]	−0.0522*** (0.000)			
	Waiting time [(min]	−0.0322** (0.029)			
	Boarding time [min]	−0.0311*** (0.000)			
	Cost [1000 won]	−0.0630*** (0.000)			
	Autonomous mode (1: Yes, 0: No)	0.1943** (0.016)			
	Other passengers (1: Yes, 0: No)	0.0315 (0.741)			
Case-specific variable	ASC	−0.0283 (0.974)	1.9780*** (0.007)	−0.7057 (0.655)	−2.5676** (0.021)
	Gender (1: Female, 0: Male)	−0.3682 (0.587)	−0.0868 (0.855)	1.6927 (0.302)	0.3825 (0.496)
	Age (1: ≥60s, 0: Others)	1.3680 (0.142)	0.8211 (0.116)	2.7481 (0.105)	1.6128** (0.040)
	Educational background (1: ≥University, 0: Others)	−1.3278** (0.048)	−0.8888* (0.059)	−4.0819** (0.043)	0.7915 (0.228)
	Job (1: Student, 0: Others)	0.4769 (0.571)	−0.4635 (0.462)	3.3597** (0.022)	0.5305 (0.609)
	Income (1: ≥5,000,000\, 0: Others)	−2.6300*** (0.001)	0.2635 (0.599)	−19.5404*** (0.000)	−0.5932 (0.379)
	The presence of available vehicles (1: Yes, 0: No)	−0.9901 (0.162)	−0.7805 (0.175)	1.8497 (0.298)	0.3093 (0.772)
	Main transportation mode: Subway (1: Yes, 0: No)	−0.9261 (0.152)	0.7848 (0.147)	−2.8939* (0.083)	−0.7628 (0.359)
	Main transportation mode: Bus (1: Yes, 0: No)	1.6889*** (0.007)	0.1608 (0.738)	−0.8707 (0.450)	−1.1428 (0.124)
	Main transportation mode: Taxi (1: Yes, 0: No)	−1.0871 (0.197)	−1.0843 (0.139)	−19.6986*** (0.000)	−19.6374*** (0.000)
	Main transportation mode: Private Car (1: Yes, 0: No)	0.4943 (0.484)	0.3973 (0.490)	−0.3959 (0.810)	1.3635* (0.095)
	Cost for commuting [1000 won]	−0.1819 (0.232)	−0.1634 (0.179)	−0.1168 (0.878)	−0.1862 (0.285)
	Time for commuting [min]	0.0264* (0.087)	0.0046 (0.716)	0.0285 (0.638)	0.0282 (0.139)
	Knowledge of UAM (1: Yes, 0: No)	0.0102 (0.990)	−0.3213 (0.527)	0.4527 (0.894)	0.0739 (0.905)
Model fit	Log-Likelihood	−2138.2265			
	McFadden R-square	0.2370			

*<0.1 **P < .05, ***P < .01.

subways were more likely to choose UAM over private cars in short-distance intra-city trips compared to those who do not. People who used buses still tend to use buses in inter-city trip compared to those who did not, but they were more likely to choose UAM over subways and private cars in long-distance intra-city trips. Taxi users were likely to choose UAM over taxis and private cars on inter-city trip than the others. Compared to those who do not, private car users were expected to maintain their own choices in short-distance intra-city trip and long-distance intra-city trip.

The usual commuting cost and usual commuting time do not significantly affect UAM selection in inter-city trips. However, in short-distance intra-city trips, those who spent the higher commuting cost are more likely choose UAM over subways. In addition, people who commuted for longer are less likely to choose taxis over UAM ($\beta = -0.0636$) for short-distance intra-city trips, and buses over UAM ($\beta = -0.0457$) for long-distance intra-city trips. With taxis and buses, commuting times are significantly influenced by road congestion. Therefore, individuals with longer commuting times are more likely to prefer UAM, which is not affected by road congestion. In contrast, they were more likely to choose subways over UAM ($\beta = 0.0166$) for short-distance intra-city trips. Similar to UAM, subways are not affected by road congestion. This means that there is no significant difference between the travel times of subways and UAM over short-distance travels along the same route. This could lead to a higher preference for subways, a more familiar mode of transportation, over UAM. People who were familiar with UAM were more likely to choose it in short-distance intra-city trips than those who were not. As Cho and Kim (2022) stated, awareness of UAM removes the hesitation concerning UAM.

4.3. Potential demand for UAM

Table 8 shows the probability of an individual selecting a particular alternative among the five transportation modes, which are bus, subway, taxi, private car, and UAM. Additionally, the values represent the percentage of commuters using a specific type of transportation, which is commonly referred to as modal split. The probability of an individual choosing UAM for short-distance intra-city trip is 12.69%, which is the third highest after the probability of using the subway (58.47%) and the probability of using private cars (21.31%). It was predicted that 18.40% and 13.30% of commuters would use UAM in long-distance intra-city trip and inter-city trip, respectively, implying that UAM would be the second most frequently used transportation after the subway, and its frequency would be similar to that of private cars. These results imply that UAM may be preferred over other modes, such as taxis and buses, regardless of the trip distance of commute. In addition, while the modal split of UAM is higher in long-distance intra-city trip compared to that in short-distance intra-city trip, it may decrease if the distance exceeds a certain level; for example, in inter-city trip.

Table 8
Potential demand for existing transportation and UAM.

Alternatives	Scenario		
	Short-distance intra-city trip	Long-distance intra-city trip	Inter-city trip
Bus	5.78%	5.14%	5.74%
Subway	58.47%	57.74%	66.22%
Taxi	1.75%	0.86%	1.59%
Private Car	21.31%	17.86%	13.15%
UAM	12.69%	18.40%	13.30%
Total	100.00%	100.00%	100.00%

According to Korea Transport Database, in 2018, the number of commuters per day was 135,697; 44,577; and 100,770 for the three cases: trips between Gangnam-Gu and Songpa-Gu, between Gangnam-Gu and Yeongdeungpo-Gu, and between Gangnam-Gu and Bundang-Gu. In these cases, it can be estimated that there would be approximately 17,220 (12.69% of 135,697), 8202 (18.40% of 44,577), and 13,402 (13.30% of 100,770) commuters using UAM per day in each trip. This implies that UAM can contribute to the reduction of carbon emissions and alleviating ground traffic congestion by replacing a significant portion of trips made through traditional transportation modes. Simultaneously, the widespread adoption of UAM is expected to result in a high density of aircraft, air traffic congestion, and longer waiting times for passengers, thus necessitating the development of strategies for ensuring safe UAM operations. The estimated demands for UAM in the current study differ from those presented in previous research. Among the studies conducted on SMA in South Korea, Song and Kim (2017) analyzed the modal split of buses, subways, taxis, private cars, and UAM, revealing that UAM's modal split is expected to range from 0.01% to 0.48% based on cost. These figures are significantly lower than the findings of the current study. In this regard, Song and Kim (2017) emphasized the need for further scenario analysis and SP surveys because the results did not reflect the public preferences regarding the characteristics of UAM. In contrast, Cho and Kim (2022) provided predictions similar to the results of this study by analyzing that UAM travel demand for each transit line in urban travel would range from 15,477 passengers per day to 35,301 passengers per day. In the SP survey of the current study, we explained to the respondents that UAM offers various benefits such as low noise, cost-effectiveness, short travel time, alleviation of traffic congestion, and is environmentally friendly. These may have led the respondents to perceive UAM more positively. Additionally, SP survey in this study reflected more ideal performance of UAM, which may have caused a higher preference for UAM. There is a possibility that these factors may have introduced biases in the estimation of UAM demand. Therefore, it is essential to interpret the estimated demand carefully, considering the assumptions used in survey and analysis.

Table 9 shows the changes in the probability of choosing transportation modes by alternative-specific variables that were analyzed to have a statistically significant effect on the UAM selection in each scenario. First, it was found that autonomous driving, cost, and access time of the UAM have a significant effect on the probability of using it in short-distance intra-city trip. If the UAM is operated autonomously, the probability of using the UAM increases by 2.48%. However, if the fare of UAM increased by 1000 won, the probability of choosing UAM decreases by 1.11%; furthermore, if the access time increases by 1 min, the probability of selecting the UAM decreases by 0.49%. Second, in the long-distance intra-city trip, the demand for UAM is strongly influenced in the order of cost, boarding time, and access time. If the UAM fare increases by 1000 won, the probability of choosing the UAM decreases by 1.10%. An increase of 1 min in the boarding time causes a 0.71% decrease in the probability of using the UAM, and an increase of 1 min in the access time leads to a decrease in the probability of using the UAM by 0.64%. Third, in inter-city trip, autonomous driving, fare, access time, waiting time, and boarding time affect the demand of UAM in order. UAM, which is operated by autonomous driving, causes a 1.74% increase in users. If the UAM fare increases by 1000 won, the probability of using the UAM decreases by 0.54%. A 1 min increase in the access time, waiting time, and boarding time to the UAM reduces the probability of using the UAM by 0.43%, 0.28%, and 0.26%, respectively. Moreover, in all of these cases, the change in the probabilities of using subways and private cars are the most pronounced according to the change in the probability of using UAM.

5. Discussion and conclusion

Recently, UAM has been recognized as an innovative alternative to the existing ground transportation; therefore, many private companies, major countries, and cities worldwide are striving to build an environment for UAM. Under this trend, UAM-related studies have been conducted actively since the late 2010s and recent efforts to identify the future demand for UAM have been made from various perspectives. However, relatively few studies have estimated the demand based on the potential user's intentions to choose the UAM. Furthermore, the intention of using the UAM may differ according to the city's spatial structure or behavior patterns of using existing public transportation. Nevertheless, most studies concerning psychological attitudes toward UAM have focused mainly on Western cities. The South Korean government is actively considering the introduction of UAM to solve severe traffic congestion in the city center. Therefore, this study collected SP data under the assumption that UAM will be introduced in SMA and used it to analyze the variation in the willingness of residents to use UAM depending on the characteristics of the UAM service and the socio-economic characteristics of potential users. the probability that UAM will be selected in competition with subways, buses, taxis, and private cars was estimated.

The results of this study can be summarized as follows: First, for commuting purposes, the probability of choosing UAM among subways, buses, taxis, private cars, and UAM was between 10% and 20%, with UAM being the third or second most frequently used transportation after subways and private cars. The high demand for UAM is expected to have positive effects such as reducing road traffic congestion and carbon emissions. However, this can result in air traffic congestion in urban areas and prolonged waiting times for UAM passengers. Therefore, adequate plans should be implemented for effectively managing UAM schedules and routes.

Second, the modal split of UAM was higher in long-distance intra-city trips than that in short-distance intra-city trips and inter-city trips. This suggests directions for gradually introducing UAM in the future. Lee and Hong (2021) proposed five types of operation model for UAM: airport shuttle, air metro, air taxi, MaaS, and PAV; among these, the airport shuttle that connects the airport and the city center was expected to be introduced first, followed by the air metro moving between cities or regions along a predesigned route and time in South Korea. The results of this study further advance the discussion presented by Lee and Hong (2021), demonstrating that, for commuting purposes, air metro should be first introduced for long-distance trips within a city than for

Table 9
Marginal effects of alternative-specific variables on potential demand for UAM.

Scenario	Alternatives	Variables				
		Access time [min]	Waiting time [min]	Boarding time [min]	Cost [1000 won]	Autonomous mode
Short-distance Intra-city trip	Bus	0.02%	-	-	0.05%	−0.12%
	Subway	0.36%	-	-	0.82%	−1.83%
	Taxi	0.01%	-	-	0.02%	−0.03%
	Private Car	0.10%	-	-	0.22%	−0.50%
	UAM	−0.49%	-	-	−1.11%	2.48%
Long-distance intra-city trip	Bus	0.03%	-	0.03%	0.05%	-
	Subway	0.45%	-	0.50%	0.78%	-
	Taxi	0.01%	-	0.01%	0.01%	-
	Private Car	0.15%	-	0.17%	0.26%	-
	UAM	−0.64%	-	−0.71%	−1.10%	-
Inter-city trip	Bus	0.02%	0.01%	0.01%	0.03%	−0.09%
	Subway	0.33%	0.22%	0.20%	0.42%	−1.35%
	Taxi	0.01%	0.00%	0.01%	0.00%	−0.01%
	Private Car	0.07%	0.05%	0.04%	0.09%	−0.29%
	UAM	−0.43%	−0.28%	−0.26%	−0.54%	1.74%

intra-city trips, if the total number of commuters is the same in both cases.

Third, among the service characteristics of the UAM, cost and access time were found to have a significant effect on UAM selection regardless of the trip distance. Therefore, to encourage the use of UAM, it is important to decide the appropriate fare and then select the port locations that strengthen the access to the aircrafts. In the long-term, active use can be expected when autonomous driving is introduced. Finally, the promotions for helping public understand UAM are important, and measures to promote the convenience of the elderly, who are expected to be the main user group for UAM in long-distance trips should be devised.

This study established the scenarios reflecting actual conditions of using transportation in South Korea to understand the future demand of UAM and conducted an analysis considering the subjective perception of potential users. Particularly, various factors, including both the service characteristics of UAM and the socio-economic characteristics of the respondents, were analyzed. The findings of the current study can identify the scenario where UAM adoption should be prioritized due to its high demand in South Korea. Additionally, it can provide an understanding of the necessary conditions for successful UAM implementation and active user engagement in the South Korean context.

Nevertheless, a limitation of this study is that the results of the analysis may not exactly match the actual demands owing to the nature of the SP data. Therefore, to accurately predict demand and understand the necessary conditions for encouraging UAM use, continuous research is needed for gradually introducing UAM in the future. Furthermore, it is necessary to analyze the prerequisites for UAM activation and the demand for UAM, as well as the cost and the benefits of UAM introduction.

Author contribution

Ji-Hyon Hwang: Methodology, Formal analysis, Writing-Original draft preparation, Writing-Reviewing and Editing, Visualization. Sungjo Hong: Conceptualization, Methodology, Writing-Reviewing and Editing, Supervision, Funding acquisition. All authors have read and agreed to the published version of the manuscript.

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Declaration of competing interest

None.

Data availability

Data will be made available on request.

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