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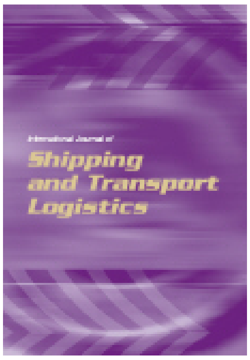

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Evaluation of factors affecting UAV selection in urban air logistics

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Abstract: Urban air mobility continues to grow in popularity and is recognised as one of the most important innovations in the aviation industry. This study aimed to identify the expectations of shippers and stakeholders regarding the use of UAVs in logistics operations. Based on academic research and industry discussions, 12 key criteria for aircraft selection were identified and categorised into technical and operational groups. Technical criteria included safety, battery/energy performance, speed, range, autonomy level, and vertical takeoff/landing capability. The operational criteria include price, security, camera system, cargo, platform tracking, and hazardous material compatibility. FUCOM, a multi-criteria decision-making method, was applied to evaluate the success of aircraft selection for air logistics stakeholders. The findings suggest that technical criteria are slightly more important than operational criteria. When all criteria were considered, safety, security, price, range, and battery/energy performance were ranked as the top five most important factors for aircraft selection in logistics operations.

Keywords: urban air mobility; UAM; logistics; MCDM; FUCOM.

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1 Introduction

The aviation sector is one of the modes of transportation that has achieved remarkable development in the last century. The current state of air transportation and goals for the near future herald a paradigm shift in air transportation. The most important factor in this change is the new aviation system, which is called urban air mobility (UAM) or advanced air mobility (AAM). Thus, if we are to define UAM, it can be stated that it refers to transportation networks that include short flights carrying people and goods in metropolitan areas. UAM is part of a larger paradigm shift towards AAM, where new technologies and business models enable transformational applications of aviation that allow aviation to play an integral role in regional and local transportation (Hill et al., 2020).

There is a very intense and increasing interest and studies on the UAM system in both the sectoral and academic sense. The world's most important institutions and organisations are working on this system. In order to bring this to fruition, numerous start-ups, aviation companies, and automobile manufacturers across the globe are dedicating resources to developing this kind of mobile aircrafts. In parallel, transportation service providers, logistics service providers and even marketing service providers are showing their intention to use this system.

This new transportation system enables point-to-point flights between cities by reducing travel times (Fu et al., 2019; Rothfeld et al., 2021; Cho and Kim, 2022) and bypassing ground congestion (Hamilton, 2018). As an example of a non-transportation service, this concept of innovative transportation facilitates the safe, sustainable, economical, and accessible conveyance of a wide variety of activities, including medical emergency missions, logistics, and surveillance (Straubinger et al., 2020). There is no doubt that it will be the future of aviation and cities. However, at this point, the areas in which this notion will contribute to people will become important. In the utopia of UAM systems, passenger transportation seems to be the biggest goal, and many studies in the literature include technical studies on passenger transportation and consumer acceptance. However, the first steps of the system are primarily based on the concept of logistics.

UAVs in the system are gaining importance, especially in urban distribution and last mile delivery. In the future, such deliveries and related aircraft will create an inevitable option and/or opportunity for an urban air logistics (UALs) system (Benarbia and Kyamakya, 2021). According to one study, with the widespread use of the system, it is predicted that the price per UAV delivery will decrease from \$6–25 to \$2 in 2034; approximately 5 million deliveries in 2024 will increase to approximately 800 million in ten years, resulting in an increase in the market share of the system from 250 million dollars to 65 billion dollars (PWC, 2024). As an example of case studies in the relevant field, the UAV manufacturer EHang states that the use of UAVs in city logistics can save 40–60% in delivery times and approximately 50% in delivery costs compared to traditional distribution systems (EHang, 2023). Fedex, one of the world's largest logistics integrators, has become ready for this system by testing its applications in commercial delivery with drones between 2019 and 2021 (Fedex, 2024). Another well-known company, DHL, stated that drones can perform operations that require fewer vehicles, are more secure, add value at lower costs, and follow and support the development of heavy-duty cargo drones (DHL, 2024). A market research study also stated that drones will not completely replace traditional systems but will be used as a support service, and yet the market is expected to grow at an increasing pace (Kumar, 2024). It is estimated that the related market will achieve a financial growth of approximately 40% by 2030, and the number of drones will reach approximately 275,000 by 2030, up from approximately 30,000 today (MarketsandMarkets, 2024).

In parallel with the developments in the sector, the number of academic studies of UAVs in urban logistics systems is increasing. In these studies, the intensity of studies on region and route planning and the structure of the organisation stands out (Troudi et al., 2017; Moshref-Javadi and Winkenbach, 2021). However, we believe that it is inevitable that the expectations and needs of UAVs will also gain importance in a market that is growing rapidly and with such great momentum.

This study aims to define a new research structure by compiling and categorising the factors influencing UAV selection in UALs. The numerical power of the research structure was verified by proving its mathematical results and formulating a weighting method based on the FUCOM method to prioritise the constituent factors. To determine the extent of factors that are useful in the selection of aircraft in terms of stakeholders in air logistics operations in the UAM system, also known as UALs, this study employed the FUCOM, a MCDM method (Rifan et al., 2022). The requirements (user expectations) of the aircraft to be used in UAL services in the context of operational and technical criteria are presented, and a priority/importance ranking of the criteria is established. This study intends to provide a roadmap and baseline analysis for businesses wishing to implement it.

Figure 1 Flowchart of study

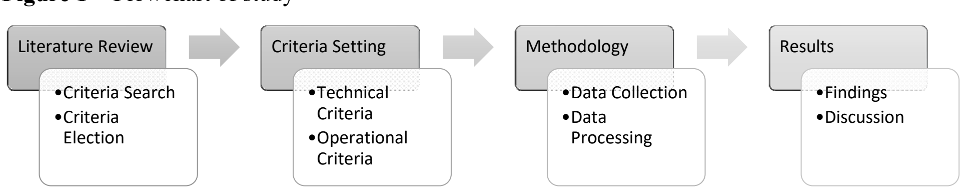


Figure 1 shows the general flow of the study. The rest of the paper is structured as follows. The positioning of our study is described, together with a description of previous research on the UAM system and logistics, in the literature review section. In the next section, studies of the criteria used in the methodology are presented. Then, in the methodology of the study, the study method is mentioned, steps are applied, and analysis and findings are included. The study concludes with a discussion, conclusion, and a reference for future studies.

2 Literature review

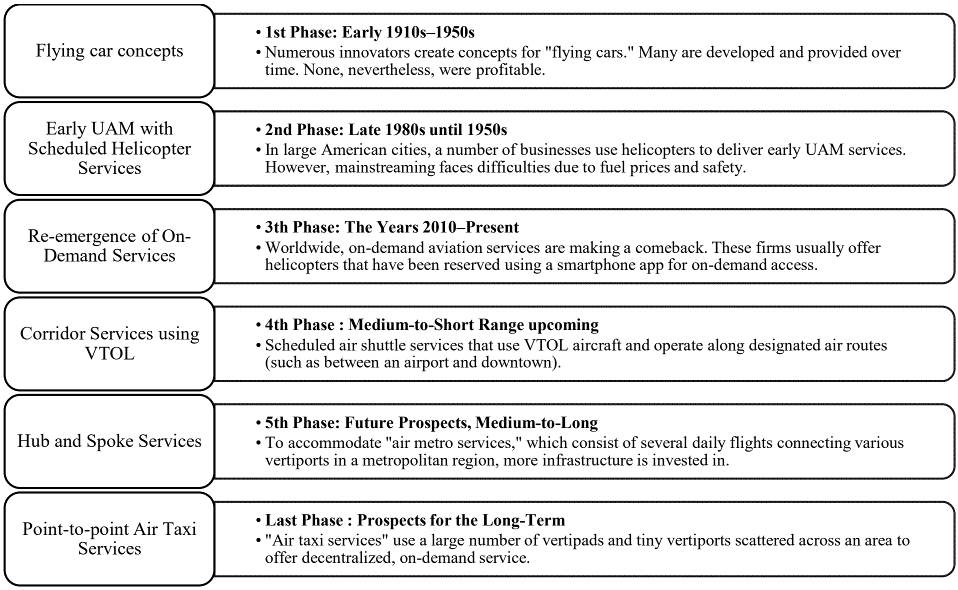
The quality and number of studies on this system have increased recently, according to an analysis of academic literature. However, these studies have mainly dealt with the technical aspects of the system or consumer acceptance. The number of studies on the intersection between UAM and logistics is quite small. This study aims to reveal the characteristics of an aircraft used in an urban logistics network, which is an important and pioneering part of the UAM system. However, while the intersection of the UAM and logistics concepts in the literature yields limited results, no similar or parallel studies have been found to the aim of the study. The literature section summarises general studies of this idea followed by logistics-related studies. To ensure the flow of the study, the literature review section was completed first through UAM, which included the general system, and then through UAL, which constituted the theme of the study.

2.1 Urban air mobility

Since the early 20th century, studies on this newly-developing mobility system have started with the concept of the ‘flying car’ and have evolved through various processes until today (Cohen et al., 2021; Qu et al., 2023). A diagram of the process is presented in the following section.

In parallel with the above chronological process, the quantity and quality of studies on UAV systems within the scope of UAM has also increased. In these studies, various models were known to be successful in their first flight (Song, 2023). Multiple types of aircraft are used in urban air transportation. These include flying taxis, which are electric vertical take-off and landing (e-VTOL) aircraft, tiny unmanned aerial vehicles (UAVs) used for recreational or commercial purposes, and manned helicopters (Tuncal and Uslu, 2021). As e-VTOL technology advances, several companies are now developing urban air vehicles: Bell, Hyundai Motors, Lockheed Martin, Embraer, Kitty Hawk, Pipistrel, Volocopter, Aurora Flight Sciences (Kleinbekman et al., 2020), Leonardo, Lilium, Terrafugia (Pradeep and Wei, 2019), EHang, Jobby Aviation, and Zee.Aero (Pradeep and Wei, 2018). These developments are attributed to the development of e-VTOL technology and their respective applications. Nevertheless, point-to-point air transportation services were offered in the 1960s in and around the cities of Los Angeles, San Francisco, New York, and Chicago (Wu and Zhang, 2021). Although its use has been attempted for a while, owing to the lack of sufficient resources and the use of different technologies, such air vehicles are still in the prototype stage (Tuncal and Uslu, 2021) and are expected to be commercialised by 2030 (Eißfeldt, 2019; Hasan, 2019; Song and Yeo, 2021; Straubinger et al., 2021; Song, 2023).

Figure 2 Six phases of UAM history and anticipated evolution



Source: Cohen et al. (2021)

In addition to UAVs, studies on the UAM, which is the whole system, have been carried out from different perspectives. Some studies have aimed to investigate people's demand and acceptance of e-VTOL in urban areas (Garrow et al., 2018; Mayakonda et al., 2020; Al Haddad et al., 2020; Straubinger et al., 2020; Rimjha et al., 2021; Bulusu et al., 2021). Some studies have investigated the design of vertiports to be used as infrastructure for UAM aircraft (Schweiger and Preis, 2022; Taylor et al., 2020). Some research has been done on the sound analysis of the aircraft (Vascik and Hansman, 2018; Eißfeldt, 2020). Some studies have evaluated it from various fields (Al Haddad et al., 2020; Koumoutsidi et al., 2022). According to Al Haddad et al. (2020), the value of trip time savings is just as important as safety and data issues in determining the technological acceptability and adoption of UAM as an alternative mode of transportation. Cho and Kim (2022) conducted a study on the environmental impacts and policy responses.

The main reason for the growing popularity of UAM researches and the prediction of its widespread use is urbanisation. According to a United Nations report, the proportion of the population living in cities was approximately 35% in the 1950s; today, it is approximately 55%, and it is estimated that this rate will reach 70% by 2050 (Song and Yeo, 2021; Marzouk, 2022; UN, 2023). According to Airbus (2023), an important stakeholder in the aviation industry, the urbanisation rate is expected to reach 60% by 2030 (Tuncal and Uslu, 2021). Assuming the accuracy of all these forecasts, capital cities as well as megacities will see thousands of daily air taxi trips (Eißfeldt, 2019). This innovative idea aims to revolutionise transportation by offering multimodal services, on-demand air travel for passengers, efficient cargo delivery, and quick response for search and rescue and emergency operations within urban areas (Koumoutsidi et al., 2022). According to experts, it will serve as a means of transportation for medical crises, leisure and tourism, disaster assistance, and establishing connections between isolated islands

(Mihara et al., 2022). In the next decade, fully autonomous vehicles are likely to be introduced with promising safe and comfortable transportation (Al Haddad et al., 2020). Grandl et al. (2018) predicted that UAM could start service in 2025, and by 2035, an estimated 23,000 of them could operate in cities with a population of approximately 5–10 million (Cho and Kim, 2022).

Hamilton (2018) discovered 36 possible markets across 16 market categories and concluded that urban air transportation can take many different forms based on vehicle technology, operations, economics, and market size. Rajendran and Srinivas (2020) investigated existing trends, future problems, and possibilities in urban air transportation. They stated challenges such as capacity forecasting, creation of urban operational infrastructure, aircraft configuration, pricing strategies, fleet maintenance, pilot training, and scheduling. In their review article, Straubinger et al. (2020) aims to provide an overview of the different areas of research on the emergence of this aerial movement. Eight major categories are used to group UAM research: aircraft, regulation, infrastructure, operations, market actors, acceptance, integration, and modelling. Garrow et al. (2021) reviewed 800 articles on this phenomenon between 2015 and 2020, including electric and autonomous vehicles. Previous reviews include ideas, modelling assumptions, methods, or conclusions that are applicable and can help inform relevant research. In his study on flying cars and urban air transportation, Marzouk (2022) gave an overview of both technologies, their advantages and disadvantages, the difficulties they face, the opportunities they present, and examples of their various states of readiness, from small-scale prototype development to commercial availability.

2.2 Urban air logistics

In addition to studies related to the above-mentioned systems, some of the limited number of logistics-related studies can be summarised as follows. UPS, one of the most famous actors in the logistics industry, tested a multimodal delivery model using trucks and drones in collaboration with a drone delivery company (Perez and Kolodny, 2017). In 2018, a study was conducted in the USA on the choice of vertiport to fulfil cargo demand between California and San Francisco (German et al., 2018). In a similar vein, DHL Express introduced the first automated urban drone delivery service on a regular basis in 2019 (Jeong et al., 2021).

In their study, Mihara et al. (2022) shown that lift-and-cruise-type flying automobiles (in respect to UAM) with multiple rotors and vector propulsion are feasible for usage in medical situations. The major requirements for the realisation of this mobility system, as demonstrated by Koumoutsidi et al. (2022) in their study, are the supply of certification criteria for its fleets and upgrading the current legal and regulatory framework. Furthermore, one of the most developed business models in the upcoming ten years will be the employment of UAM for air ambulance services or freight transportation. Yavaş and Tez (2021) predicted in their study that this notion’s use in cargo transportation would increase. According to Rajendran and Srinivas (2020), several logistics firms and aviation organisations, it will be utilised through flying taxi services, an aircraft hailing idea that is anticipated to be introduced soon. Approximately 86% of deliveries might match the UAV logistics capacity requirements, according to statistics analysed by Amazon based on parcel weight (Yi et al., 2023). NASA has suggested that UAV logistics should handle 500 million package delivery service orders by 2030 (Yi et al., 2023). In this sense, various studies have been conducted on consumer behaviour regarding the use of drones in urban logistics. Melo et al. (2023) did a study in Portugal which shown that consumers hold a positive attitude towards the usage of drones in urban logistics. They are willing to pay for the potential environmental advantage rather than a shorter delivery time. In parallel with sustainability and environmental concerns, there is a trend towards greener and more efficient transportation using drones in last-mile delivery in local distribution for companies that want to retain their competitiveness (Eskandaripour and Boldsaikhan, 2023). In another similar study, the details of a joint combined transportation operation of drones and trucks in last mile delivery were revealed (Moshref-Javadi and Winkenbach, 2021).

When the literature review is summarised under the two headings above, studies on the intersection of UAM and aircraft, UAM and Logistics are included. However, no similar studies have been found on the characteristics and/or qualifications of aircraft to be used in UAM and logistics systems, which is the aim of this study. A limited number of studies that include all these intersections address the limitations of aircraft regarding battery management in logistics network management (Golden et al., 2023). In another study conducted on UALs, although the characteristics of the aircraft were not discussed directly, it was stated that factors such as privacy, noise, safety, and environment are important in choosing aircraft (Rifan et al., 2022). In another similar study, while the importance of full automation of the aircraft was emphasised, safety concerns were also expressed (De Silvestri et al., 2022). However, in this limited number of studies, there is no holistic approach to the aircraft characteristics/capabilities required for UALs. To achieve this goal, a compilation of aircraft characteristics included in similar studies under the following heading was made, and the most appropriate qualifications were created. The criteria that stand out in these studies are the expectations of aircrafts to be used in air logistics.

3 Determining the aircraft criteria

This section summarises the literature used to identify the factors that influence aircraft selection for use in UALs operations. During the literature review, especially the EASA, various criteria were encountered from different sources regarding the use of UAVs in logistics operations. In this context, all relevant criteria were evaluated to consider all the studies and cover the system. A review of the literature reveals that no approach evaluates aircraft characteristics and capabilities as a whole. Studies that have been conducted lack the depth of the purpose of this study. In this context, in order to address this gap in the literature, studies that include aircraft characteristics and capabilities in non-integrated studies were examined. The criteria in these studies were carefully selected with a comprehensive evaluation based on the literature in light of the opinions of three academician experts (who are also involved in the criteria evaluation process) who have valuable studies in the field. This approach provides a balanced decision-making process regarding aircraft characteristics/capabilities required for UALs. With this approach, the decision-making process regarding aircraft characteristics/ capabilities can be facilitated, thus enabling the efficient and effective implementation of UALs. To improve the flow and clarity of the study, the criteria obtained are given under two main headings: technical and operational.

3.1 Technical criteria

In addition to legal, technical, and economic regulations related to air transportation, safety is undoubtedly one of the first factors to come to the fore in academic studies. Safety is an important consideration for any system that deals with people (Taylor et al., 2020). Over the previous 20 years, air traffic in the aviation sector has expanded by more than 86%, yet accident rates have declined dramatically across all aircraft generations, demonstrating that safety expenditures have resulted in considerable gains (Cokorilo, 2020). A negative situation related to safety causes resistance not only among passengers using this mode of transport but also among community members who are not engaged in UAM travel (Marzouk, 2022). Appropriate regulations are essential to ensure the safe operation of these aircrafts (Straubinger et al., 2020). The requirements for safety and certification provide a significant barrier to commercial aviation operations in cities. Currently, relevant certification regulations are being considered, particularly by the Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA) (Straubinger et al., 2020). Safety is important to the businesses designing this type of an aircraft, as they have mentioned on their advertising pages. Safety is the first priority, according to Wisk Aero (2023), a joint venture between Boeing and Kitty Hawk Corporation that was founded in 2019. Similar to this, Airbus emphasises how crucial safety is to all of its operations on the promotional page for the CityAirbus NextGen concept. CityAirbus NextGen is expected to comply with the most rigorous certification standards. The statement on the Lilium (2023) Jet web page to emphasise safety is "one of the only pioneers in e-VTOL seeking dual certification with EASA and FAA."

Battery/energy performance is another important criterion for aircraft in UAM systems. Many studies have emphasised this point in the literature. According to Garrow et al. (2021), the efficiency, cost, and long-term viability of its networks will be directly impacted by vehicle-level factors like charging time or energy required during a flight. Air vehicles that will take part in this system are expected to be e-VTOLs, and for this reason, studies on energy and charging-related processes are also being carried out. It is stated that the batteries used in aircraft have two different charging modes, fast and slow, but considering that each of them has its own characteristics and makes the best use of a fleet in the management of the UAM process, reducing costs and thus preserving battery life will make a difference (Bennaceur et al., 2022).

In an environment where air transportation is mentioned, speed is of course one of a criterion that cannot be ignored. This criterion has also been emphasised in various studies. UAM can save travel time for 3–13% of motorised trips (Rothfeld et al., 2021). Lilium, one of the key stakeholders of in this sector, states that the system will reduce the travel time between Orlando and Tampa to 30 minutes compared with a two-hour car trip (GreenBiz, 2021). According to EHang's estimates, if logistics activities are carried out with this, compared to traditional logistics, 40% to 60% savings in delivery time and scaled delivery are expected to reduce costs by 50%.

Another prominent criterion for aircraft selection in this system is distance or range. UAM is generally defined as an aircraft with a range of up to 200 miles and a capacity of 2–6 passengers (Yedavalli and Mooberry, 2019). Undoubtedly, one of the factors determining the distance in one of these systems is aircraft type. At this point, the high-capacity and high-speed capabilities of fixed-wing aircraft are higher than those of rotary-wing aircraft; however, their hover and VTOL capabilities are more limited (Chipade et al., 2018). Considering these limitations in logistics operations, aircraft designs that can provide speed, distance, ease of use, and efficiency are expected to be important challenges for the sector.

When discussing a UAM system, it is not possible to ignore its autonomous level. Autonomy is certainly one of the most important elements that differentiates a system from conventional air transportation. It is characterised as an autonomous transportation system that uses low-altitude aircraft that are either human-piloted or autonomous to move people or goods within cities, between cities, or across suburban areas (Marzouk, 2022). Competence at the autonomous level also makes a significant difference in both passenger and logistics operations within this system. For example, EHang, one of the important actors in the sector, claims that the aircraft it offers for logistics activities can complete its mission by flying along a pre-programmed route, there will be no need for any manual intervention, and thus the delivery will take place efficiently and safely (EHang, 2023).

Vertiport is the last criterion that stands out among the technical criteria. As airports and heliports have a large share of the air transportation system, they are expected to share a similar share of the UAM system. Vertiports are an essential component of this system, and their effectiveness is directly related to the system's overall performance (Taylor et al., 2020; Rimjha and Tirani, 2021). At different locations throughout the city, vertiports will be built to facilitate quick access to air taxis, transfer to other forms of transportation, and technical assistance with things like battery replacement, charging, and upkeep (Eißfeldt, 2019). This runs counter to the need for air taxis to be as small as possible in order to fit within urban spaces that are limited in size. The manufacturing of UAM stations may be constrained by the size of the aircraft due to the restricted amount of accessible space (Straubinger et al., 2020). It is intended to use vertiports on rooftops (Air One), in the ground (Terra One), and in the ocean (Marine One) (Schweiger and Preis, 2022). The following are examples of these types of locations: parking lots at places of worship that are only used on weekends; large stadiums or concert halls that are not used for most of the year; parking corners in department stores or shopping malls; technology campuses; floating barges [Garrow et al., (2021), p.16; Ahn and Hvang, 2022]; highway interchanges (Ahn and Hvang, 2022).

As a result of the review of the relevant studies in the literature, the authors evaluated the criteria of "safety, battery/energy performance, speed, distance/range, autonomy level, and vertiport" as the prominent criteria without any order of importance under the technical criteria.

3.2 Operational criteria

In addition to the technical criteria detailed above regarding the overall structure and rollout of the UAM system, there are also operational criteria that are important for logistics stakeholders in the use of the system.

Price is undoubtedly one of the most prominent criteria for stakeholders. Because the system is not currently operational, it can be said that the price is mostly a matter of guesswork at this stage. The cost of service owing to capital requirements is expected to be high in the short-term market (Rajendran and Srinivas, 2020). Uber Elevate stated during the introduction of its on-demand air taxi that service costs are projected to be \$5.73 per person-mile, but they should decrease to \$1.84 in the near future as ride-hailing usage increases. According to Uber Elevate, flight operation costs will be around half of what helicopters currently operate for $2.00 per passenger mile and the costs of a five-seat e-VTOL conducted for NASA are estimated at USD 6.25/person-miles per year (Garrow et al., 2021). This futuristic mode of transportation's exorbitant costs and quick transit speeds make its long-term effects particularly interesting. First, a user group must be willing to pay for the reduction in travel time due to the combination of high costs and high travel speeds (Straubinger et al., 2021).

Security is another operational issue highlighted in industry news and academic studies. Here, security refers to the risk of loss, damage, and theft of the cargo being transported and issues related to the confidentiality/privacy of the cargo and certain areas (military and private property). In addition to being inconvenient or uncomfortable, the capacity to hover at low altitude over visually exposed single-family homes has implications for certain business sectors, such resorts, and national security (e.g., it is unacceptable to hover near military zones) (Marzouk, 2022). Furthermore, governments can address the risks associated with vertiport/aircraft physical security, personnel security, and cyber security – security-related elements that cast doubt on consumer acceptance of these systems – by enacting regulatory measures (Choi and Park, 2022).

In the introduction and development of the UAM system, it is mentioned that cameras and recording systems are important parts of aircrafts. At the beginning of the widespread use of this system, it was thought that the presence of visual aids is important for various reasons, especially for safety and security reasons. For example, visual aids, especially cameras, may be needed to detect landing areas, estimate their positions, detect and avoid fixed and moving obstacles, and safely perform landing and take-off procedures in any operation (Veneruso et al., 2022).

Owing to the main problem of this study, the payload, that is, the maximum payload capabilities of the aircraft used, is also a prominent issue. The change and popularity of the e-commerce and retail sectors creates a mandatory challenge in logistics processes. Consumers demand a more frequent and wider range of products, and businesses face an uphill struggle to deliver them on time. Studies on UAV systems and the development of payload-capable vehicles for consumers in difficult terrains and remote areas, or for time-sensitive products, have attracted interest as a reasonable solution (Chipade et al., 2018). However, the small, lightweight, and highly mobile bodies of UAM aircraft are more suitable for the transportation of small packages. However, the sector's increasing need for capacity for heavy loads and the demand moving in this direction necessitate advanced engineering studies on the structural features of the aircraft (Geuther et al., 2018). For example, one of China's largest retailers is testing aircraft with a capacity of up to 1,000 kilogram to be able to deliver its heavier goods in addition to its small deliveries to rural areas (Moshref-Javadi and Winkenbach, 2021).

Another option is to monitor the relevant aircraft through a platform as the UAM system is built on digital elements. At this point, possible air traffic density and airspace management issues are important. It is emphasised that the system, whose popularity is increasing daily by all stakeholders, will also have a high density during the use phase. Therefore, it is important to ensure that the system is tracked through a platform for air traffic management and information sharing services (Tang et al., 2021). The China-based manufacturer EHang (2023) also states that, especially in logistics operations, the tracking of aircraft through the system will contribute to ensuring the safety of operations with real-time monitoring and analysis for each flight.

Finally, because the aircraft to be used will essentially be part of the logistics operation, in some cases the cargo they carry may fall within the scope of hazardous materials or dangerous goods. At this point, the suitability of the relevant aircraft for hazardous materials is also considered to be an issue to be taken into consideration. Hazardous materials transportation carries certain risks for all modes of transportation, and these logistics services are carried out within the framework of certain standards. Air transportation also includes regulations with the highest constraints among all transportation modes. Therefore, surface transportation modes still have the highest share in the transportation of dangerous goods. However, given the potential harm to both people and the environment, the dangers associated with surface transportation modes cannot be disregarded. Many manufacturers are working on creating drones that can move dangerous products in a safe manner. By transporting specific cargoes, these initiatives hope to lower costs and land traffic congestion in addition to lowering the danger of accidents (Bridgelall, 2022).

As a result of the review of the relevant studies in the literature, the authors evaluated "price, security, camera recording system, payload, tracking through the platform, and suitability for hazardous materials" as the prominent criteria without any order of importance under operational criteria.

4 Research methodology

4.1 FUCOM method

The full consistency method (FUCOM) method, which is a multi-criteria decision-making MCDM method, provides subjective weighting and is relatively new. This concept was introduced by Pamučar et al. (2018). This MCDM method is increasingly used in many different fields such as logistics centre location (Yazdani et al., 2020), evaluation of quality determinants in reverse logistics (Stevic et al., 2021), site selection for textile production (Ulutaş and Karakuş, 2021), storage area selection (Badi and Kridish, 2020), wind power plant site selection (Ecer, 2021), mapping of mining potential (Feizi et al., 2021), selection of wastewater treatment technologies (Srivastava and Singh, 2021), airline selection (Mahendra, 2022), airport evaluation (Baki, 2022), influencer selection for food industry (Shirkhodaie et al., 2022), UAV selection (Radovanović et al., 2023), evaluation of cyber security systems (Kayişoğlu et al., 2024), and supplier evaluation (Hashemi-Tabatabaei et al., 2024). This method combines aspects of the best-worst method (BWM) and the analytical hierarchy method (AHP) to create priority weights for a set of predetermined criteria. FUCOM is not similar to these approaches in two ways:

1 Coherence between the relative priorities of these qualities and attribute relation weights.

2 Transitivity in mathematics: By minimising the deviation from the full consistency (DFC) metric linked to these two sets of constraints, the model establishes the priority weights of the attributes (Ocampo, 2022).

Furthermore, this approach enables the calculation of criterion weights in a more reliable manner (Özdağoğlu et al. 2021).

The level of consistency is important for validating the findings of a method. Inconsistency increases if mathematical transitivity is violated when comparing the criteria in a pairwise problem. In particular, when the number of criteria is high, a large number of comparisons makes it difficult to apply the model. For example, in AHP, $n.(n - 1)/2$ and in BWM $(2n - 3)$ comparisons are made. The FUCOM method required fewer pairwise comparisons $(n - 1)$. In other methods, the level of consistency is only one, which in some cases indicates a high level of subjectivity. In the FUCOM method, interval values of the weight coefficients are created, and these values are taken as the final values of the criterion weight. It is also recommended to determine the mean values of the intervals using the FUCOM method. However, if the findings are inconsistent, there is no guarantee that the optimal values of the weight coefficients will be within the specified ranges (Majumder, 2023).

The FUCOM method consists of three basic steps (Pamučar et al., 2018):

Step 1 *Ranking the criteria:* In this step, decision-makers rank the criteria from the most important to the least important criteria ($C = \{C_1, C_2, \ldots, C_n\}$). Equation (1) illustrates the criteria that were ordered based on the weight coefficients' predicted values.

$$C_{j(1)} > C_{j(2)} > C_{j(k)} \tag{1}$$

Step 2 *Determine the importance of criteria:* In the second step, the ranked criteria are compared, and their comparative priorities ($\varphi_{k/(k+1)}$, $k = 1, 2, \ldots, n$, where k represents the rank of the criteria) are determined by the decision-maker. Equation (2) illustrates the vectors of the comparative priority of the evaluation criteria that were derived.

$$\phi = \left(\varphi_{1/2}, \varphi_{2/3}, \ldots, \varphi_{k/(k+1)}\right) \tag{2}$$

The FUCOM approach compares criteria pairwise using values from another measuring scale, integer values, or decimal values. In this study, a paired comparison scale (1–9) was employed.

Step 3 *Find the final values of the weight coefficients:* In this step, the final values of the weight coefficients of the criteria are determined $(w_1, w_2, \ldots, w_n)^T$. The weight values obtained must fulfil the following two conditions:

- *Condition 1:* The ratio of the weight values must be equal to the comparative importance between the observed criteria ($\varphi_{k/(k+1)}$) in step 2. Namely like equation (3):

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \tag{3}$$

- *Condition 2:* The final values of the weight coefficients must ensure the mathematical transitivity. Namely:

$$\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$$

Also, since $\varphi_{k/(k+1)} = \frac{w_k}{w_{k+1}}$ and $\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$, $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}}$ is obtained. Thus, condition 2, under which the final values of the weight coefficients of the criteria must be fulfilled, is obtained as shown in equation (4).

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \tag{4}$$

Full consistency, i.e., *minimum* $DFC_{(X)}$, only happens when transitivity is fully satisfied. Thus, the DFC value for the weight coefficient obtained by fulfilling the maximum consistency condition is $(X) = 0$. The DFC values at which the weight coefficients are acceptable or close to the optimal values are in the range [0, 0.025]. In order for the conditions to be met, the values of the weight coefficients $(w_1, w_2, \ldots, w_n)^T$ must be determined by minimising the value of (X), equalities $\left| \frac{w_k}{w_{k+1}} - \varphi_{k/(k+1)} \right| \le \chi$ and $\left| \frac{w_k}{w_{k+2}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \right| \le \chi$ must be satisfied.

In this way, the maximum consistency condition is fulfilled. In this environment, the final model for determining the final values of the weight coefficients of the criteria is defined as in equation (5).

$$\min \chi \begin{cases} \left| \frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)} \right| \le \chi, & \forall j \\ \left| \frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \right| \le \chi, & \forall j \\ \sum_{j=1}^{n} wj = 1, \; wj \ge 0, & \forall j \end{cases} \tag{5}$$

When the model in equation (5) is solved, the final weight values of the criteria $(w_1, w_2, \ldots, w_n)^T$ and the degree of $DFC_{(X)}$ are obtained.

4.2 Analysis and findings

This study was conducted using the FUCOM method, a MCDM method, to reveal the degree of factors that are effective in aircraft selection in terms of air logistics stakeholders. This method validates the model by calculating the error for the resulting weight vectors, while maintaining consistency between the comparisons. Given that the weight coefficients have a significant influence on the final solutions, they reduce the subjectivity in the decision-making process. The mathematical structure of this method increases the accuracy and reliability of the weight calculation. That is, it makes it possible to obtain reliable weight coefficients that help rational decision-making and lead to credible decision-making results. Therefore, decision-makers are more confident in the results obtained. These advantages make FUCOM an important tool in MCDM, helping decision makers solve complex problems and make effective decisions. In fact, the FUCOM method was used in this study owing to these advantages. The study was not prepared for a group or specific sector. In this context, while determining the experts, experts from sectors expected to be stakeholders in UAM logistics operations are preferred. In addition, as there is no specific sector, academics who are experienced in their field and have studies in this field were also included in the study as experts.

The purpose of this study is to identify the variables that affect aircraft choice, such as those involved in air logistics. Studies on MCDM may have a restricted number of specialists (Çıkmak et al., 2023). Seven specialists were consulted for the study. Additionally, there are few professionals in this industry because they are relatively new. Choosing the right expertise is essential to obtain accurate data for MCDM research. Therefore, experts with knowledge of the UAM development process are preferred in this study. Four of the sector representatives included in the study had 20 or more years of experience. The three participants, included as academicians, had an average of 10 years of experience. Among the sector representatives, four worked as senior managers at high-level logistics companies. Two of them work as senior managers in international air cargo companies. Academicians participating in this study have also conducted important international studies in the fields of air cargo and logistics.

Table 1 Main criteria and sub-criteria

Main criteria (C)	*Sub-criteria*	*Definitions*	*Code*
Technical criteria (C1)	Safety	Adequacy against situations such as damage and accidents	T1
	Battery/energy	Aircraft usage time, charging time, etc.	T2
	Speed	Maximum speed of the aircraft	T3
	Distance/range	Altitude/height and maximum range/distance of the aircraft	T4
	Autonomy level	Whether fully autonomous, semi-autonomous or pilot-controlled	T5
	Vertiport requirement	The need for any infrastructure/landing-landing area requirement	T6
Operational criteria (C2)	Price	The tariff/fee to be applied by the aircraft/operator based on kilogram and distance	O1
	Security	Theft of the cargo or concealment of its contents/protection of privacy	O2
	Camera and recording systems	Recording and monitoring of the aircraft with an integrated camera throughout the flight	O3
	Payload	Max. cargo load it can carry	O4
	Tracking via platforms	Tracking the aircraft through any system (GPS, etc.)	O5
	Dangerous goods availability	Legal and technical conformity of the aircraft for the transportation of dangerous goods	O6

Research data were obtained using a survey technique. The criteria used in this study were obtained from a literature review. According to data obtained from the literature, the criteria group was divided into two main groups: technical and operational. The main and sub-criteria are listed in Table 1.

In Table 2, the criteria that make up the model are ranked by seven expert decision-makers from the most important criterion to the least important criterion. Main criteria are denoted by *C*. The sub-criteria are in two sub-groups: technical criteria are denoted by *T*, and operational criteria are denoted by *O*.

Table 2 Ranking of criteria according to their importance level

Decision-makers (DM)		*Main criteria (C)*	*Sub-criteria*	
			Technical criteria (T)	*Operational criteria (O)*
1	DM	C2 > C1	T1 > T2 = T4 > T5 > T3 > T6	O1 > O2 = O3 = O5 > O4 > O6
2	DM	C1 > C2	T1 > T4 > T5 > T2 > T3 > T6	O2 > O1 > O5 > O4 > O3 > O6
3	DM	C1 > C2	T1 > T6 > T2 > T4 > T3 > T5	O1 > O2 > O4 > O5 > O3 > O6
4	DM	C1 > C2	T1 > T4 > T2 > T6 = T5 > T3	O2 > O1 = O6 > O3 = O5 > O4
5	DM	C1 > C2	T1 > T2 > T4 > T6 > T3 > T5	O1 > O4 > O2 > O5 > O3 > O6
6	DM	C2 > C1	T4 > T2 > T5 > T6 = T3 > T1	O2 > O1 > O4 = O5 > O3 > O6
7	DM	C2 > C1	T1 > T6 > T5 > T4 = T2 > T3	O2 > O5 > O3 = O1 > O4 > O6

Table 3 Comparative priorities for main and sub-criteria

Decision-makers (DM)			*Main criteria (C)*		*Sub-criteria*											
					Technical criteria (T)						*Operational criteria (O)*					
1	DM	Ranking	C2	C1	T1	T2	T4	T5	T3	T6	O1	O2	O3	O5	O4	O6
		Priorities	1	7	1	3	3	4	9	9	1	2	2	2	5	9
2	DM	Ranking	C1	C2	T1	T4	T5	T2	T3	T6	O2	O1	O5	O4	O3	O6
		Priorities	1	3	1	3	5	6	7	9	1	3	5	7	8	9
3	DM	Ranking	C1	C2	T1	T6	T2	T4	T3	T5	O1	O2	O4	O5	O3	O6
		Priorities	1	3	1	5	6	7	8	9	1	2	3	5	7	9
4	DM	Ranking	C1	C2	T1	T4	T2	T6	T5	T3	O2	O1	O6	O3	O5	O4
		Priorities	1	8	1	6	7	8	8	9	1	6	6	7	7	9
5	DM	Ranking	C1	C2	T1	T2	T4	T6	T3	T5	O1	O4	O2	O5	O3	O6
		Priorities	1	3	1	3	4	6	7	9	1	3	4	6	7	8
6	DM	Ranking	C2	C1	T4	T2	T5	T6	T3	T1	O2	O1	O4	O5	O3	O6
		Priorities	1	3	1	3	4	5	5	6	1	3	5	5	7	8
7	DM	Ranking	C2	C1	T1	T6	T5	T4	T2	T3	O2	O5	O3	O1	O4	O6
		Priorities	1	7	1	3	5	6	6	7	1	3	5	5	6	9

The ‘>‘ sign in Table 2 indicates that the criterion on the left is more important than the one on the right, while the ‘=‘ sign indicates that the two criteria are equally important. After ranking the main and sub-criteria from the most important criterion to the least important criterion, the decision-makers determined the priority of the most important criterion over the other criteria. The comparative priorities of the criteria were determined according to an importance scale of to 1–9 (1 = equally important, 9 = extremely important). The comparative priorities determined for the main criteria and sub-criteria are presented in Table 3.

Table 3 shows the comparative priorities for the main criteria and sub-criteria. The comparative priorities show that the main criteria for decision-maker 1 are operational criteria (O). According to this decision-maker, operational criteria are 7 points more important than technical criteria (T). The evaluations for the sub-criteria shown in Table 3 are based on similar logic. For example, the most important technical sub-criterion for decision-maker 1 is safety (T1). The least important technical sub-criterion is the need for a vertiport (T6). For this decision-maker, the criteria T2 and T4 (T2 = T4) are of equal importance. This importance was 3 with respect to the first criterion. These criteria are followed by the level of autonomy (T5), speed (T3), and need for vertiport (T6) with importance degrees of 4, 9, and 9. As can be seen, criteria T3 and T6 are equally important.

The comparative priorities of all the criteria were calculated when the steps of the method were applied sequentially. For example, in Table 3, the comparative priorities of the first decision-maker for the technical sub-criteria are calculated as follows:

$$\varphi_{T1/T2} = 3/1 = 3,\ \varphi_{T2/T4} = 3/3 = 1,\ \varphi_{T4/T5} = 4/3 = 1.33$$
$$\varphi_{T5/T3} = 9/4 = 2.25 \text{ ve } \varphi_{T3/T6} = 9/9 = 1$$

Criteria weights were calculated using comparative priorities (Table 3) for all the criteria. As stated in equation (3), the ratio of weight coefficients should be equal to the comparative priority of the criteria. As a result of decision-maker 1's evaluations, the ratio of the weight coefficients for the technical sub-criteria is calculated as follows:

$$w_{T1/T2} = 3,\ w_{T2/T4} = 1,\ w_{T4/T5} = 1.33,\ w_{T5/T3} = 2.25 \text{ ve } w_{T3/T6} = 1$$

The final values of the weight coefficients must satisfy the mathematical transitivity condition given in equation (4). In this case, the value of the 1st technical sub-criterion with respect to the 4th technical sub-criterion in line with the assessments of decision-maker 1 is calculated as follows:

$$\frac{w_1}{w_4} = w_{1/3} \times w_{3/3} = 3x(3/3) = 3$$

To obtain the final criteria weights of the technical sub-criteria as a result of the evaluations of decision-maker 1, the linear programming model specified in equation (5) was established.

$$\min \chi \begin{cases} \left|\frac{w_1}{w_2} - 3\right| \le \chi, \left|\frac{w_2}{w_4} - 1\right| \le \chi, \left|\frac{w_4}{w_5} - 1.33\right| \le \chi, \left|\frac{w_5}{w_3} - 2.25\right| \le \chi, \left|\frac{w_3}{w_6} - 1\right| \le \chi \\ \left|\frac{w_1}{w_4} - 3\right| \le \chi, \left|\frac{w_2}{w_5} - 1.33\right| \le \chi, \left|\frac{w_4}{w_3} - 3\right| \le \chi, \left|\frac{w_5}{w_6} - 2.25\right| \le \chi \\ \sum_{j=1}^{6} w_j = 1,\ w_j \ge 0,\ \forall j \end{cases}$$

When the model was solved in Excel, the final weights of the technical sub-criteria for decision-maker 1 were $w_1 = 0.468$, $w_2 = 0.156$, $w_3 = 0.052$, $w_4 = 0.156$, $w_5 = 0.117$, $w_6 = 0.052$. The calculated weight values were rounded up to three digits after the decimal point. The DFC values were 0.

Linear programming models were created for each decision-maker by considering the evaluations of all decision-makers for the main and sub-criteria. By solving these models, the importance weights of the main criteria were calculated, as shown in Table 4, and the importance weights of the sub-criteria were calculated, as shown in Table 5. The local weights were calculated by averaging the weights calculated separately for each decision-maker.

Table 4 Weight coefficients of main criteria

(DM)	*C1*	*C2*
1 DM	0.889	0.111
2 DM	0.125	0.875
3 DM	0.750	0.250
4 DM	0.750	0.250
5 DM	0.750	0.250
6 DM	0.250	0.750
7 DM	0.125	0.875
Local weights	*0.520*	*0.480*

In Table 4, the main criteria weights are calculated. According to the results, the technical main criterion (C1) ranked first with 0.520 points, while the operational main criterion (C2) ranked second with 0.480 points. When the decision of the first decision-maker is analysed, the technical main criterion (C1) is 0.889 points and the operational main criterion (C2) is 0.111 points. According to the second decision maker, the operational main criterion (C2) was 0.875 points and the technical main criterion (C1) was 0.125 points.

In Table 5, sub-criteria weights are calculated. When the local weights of the technical sub-criteria are analysed, the safety criterion (T1) ranks first with 0.461 points, whereas the speed criterion (T3) ranks last with 0.071 points. When the operational sub-criteria are analysed according to the local weights, it is seen that the safety (O2) criterion ranks first with 0.374 points, whereas the hazardous material suitability (O6) criterion ranks last with 0.060 points.

Finally, the global weights of all the sub-criteria are calculated. These weights were obtained by multiplying the main criteria weights given in Tables 4 and 5 by the local weights of the sub-criteria. The final calculated criteria weights are presented in Table 6.

Table 6 lists the calculated local and effective weights for all criteria. The results show that the technical main criterion (C1) ranks first with 0.520 points, and the operational main criterion (C2) ranks second with 0.480 points. According to the effective weight ranking, including all sub-criteria, the safety (T1) criterion ranked first with 0.240 points, whereas the hazardous material availability (O6) criterion ranked last with 0.029 points. The Vertiport requirement (T6) and payload (O4) are equally important, with a score of 0.048 and ranked seventh.

Table 5 Weight coefficients of sub-criteria

DM	*Sub-criteria*											
	Technical criteria (T)						*Operational criteria (O)*					
	T1	*T2*	*T3*	*T4*	*T5*	*T6*	*O1*	*O2*	*O3*	*O4*	*O5*	*O6*
1 DM	0.468	0.156	0.052	0.156	0.117	0.052	0.356	0.178	0.178	0.071	0.178	0.040
2 DM	0.512	0.085	0.073	0.171	0.102	0.057	0.174	0.523	0.065	0.075	0.105	0.058
3 DM	0.573	0.095	0.072	0.082	0.064	0.115	0.437	0.219	0.062	0.146	0.087	0.049
4 DM	0.599	0.086	0.067	0.100	0.075	0.075	0.096	0.578	0.083	0.064	0.083	0.096
5 DM	0.499	0.166	0.071	0.125	0.055	0.083	0.496	0.124	0.071	0.165	0.083	0.062
6 DM	0.078	0.155	0.093	0.465	0.116	0.093	0.167	0.500	0.071	0.100	0.100	0.062
7 DM	0.500	0.080	0.071	0.080	0.100	0.170	0.099	0.497	0.099	0.083	0.166	0.055
Local weights	*0.461*	*0.118*	*0.071*	*0.168*	*0.090*	*0.092*	*0.261*	*0.374*	*0.090*	*0.101*	*0.115*	*0.060*

Table 6 Weight coefficients of criteria and ranking

Main criteria	*Sub-criteria*	*Local weights*	*Effective weights*	*Ranking*
C1 (0.520)	T1	0.461	0.240	1
	T2	0.118	0.061	5
	T3	0.071	0.037	10
	T4	0.168	0.088	4
	T5	0.090	0.047	8
	T6	0.092	0.048	7
C2 (0.480)	O1	0.261	0.125	3
	O2	0.374	0.180	2
	O3	0.090	0.043	9
	O4	0.101	0.048	7
	O5	0.115	0.055	6
	O6	0.060	0.029	11

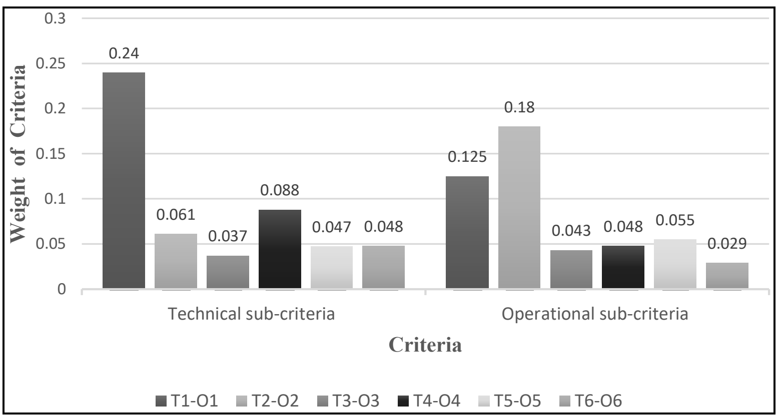
5 Discussion

The importance of UAM systems is becoming increasingly familiar to many stakeholders. Although the main goal of these systems is the future of aviation, logistics operations will come to the forefront in the process of system deployment as a secondary goal. This study aims to reveal the expectations of stakeholders, that is, shippers, from the UAM aircraft to be used in logistics operations. As a result of academic studies and sectoral sharing of this mobile system and logistics, 12 prominent aircraft selection criteria were identified. These criteria are classified into two main headings: technical and operational. Under the technical criteria, "safety, battery/energy performance, speed, distance/range, autonomy level, and vertiport" criteria were determined without any ranking of importance. Under operational criteria, "price, security, camera recording system, payload, platform tracking, and suitability for hazardous materials" criteria were determined without any ranking of importance.

As a result of the findings, it was concluded that technical criteria are more important than operational criteria, with a small difference. Because operational criteria may create different expectations according to the operations of the relevant stakeholders and because each operation may have its own specific conditions, it can be predicted that the criteria may vary. However, because the technical criteria, that is, the pre-operational qualifications of the aircraft, are the most fundamental and unchangeable characteristics, they will be at the centre of all operational processes. For this reason, it is expected that technical criteria are more important than operational criteria.

There is no coincidence that safety, which is one of the primary objectives of air transportation, ranks first among the technical criteria. It is also a fact that distance/range and battery/energy performance criteria, which rank 2nd and 3rd, are interrelated. When external factors such as meteorological conditions are ignored, it is expected that the aircraft will cover as much distance as its battery. As a result, the study's findings are reliable and significant. Stakeholders did not rank the technical criteria's degree of autonomy as a high priority. This did not make a difference to the logistics stakeholders because the aircraft currently used in logistics operations are autonomous rather than the passenger transportation target in the UAM system. Within the system, the level of autonomy is a determining factor, mainly in passenger transportation operations. Therefore, it can be considered a normal result that the autonomy level does not stand out in logistics operations. Finally, the speed factor, which is considered to have the least importance in the technical criteria, can be considered as one of the most surprising results in the ranking of all criteria in the study. Speed is one of the most important symbolic features of air transportation. Since emergency situations and urgent deliveries come to mind first in drone logistics operations, it can be said that the importance of speed is ignored here. On the other hand, the fact that air transportation and drones will be faster than other modes of transportation owing to their nature may have been subjected to low scoring in the evaluation as a feature that is already expected to exist in terms of stakeholders' perception.

Figure 3 Weight coefficients of criteria



Security and privacy rank first among the operational criteria in terms of importance. Participants ranked security as the second most essential criterion in the overall rating, after safety. As far as the effectiveness, integrity, and sustainability of the system with the confidence earned are concerned, security concerns in all its forms will rank among the most crucial factors. The price/fee factor is evidently one of the most significant criteria, right after security. In addition to the new and high-tech features of the UAM system, the perception that air transportation is traditionally considered the most expensive mode of transportation has brought the price criterion to the highest point in the related-logistics operations. Among the operational criteria, tracking aircraft through a digital platform was also considered an important criterion by participants. This is understandable as a habit and requirement of cargo tracking systems, even in relatively simple road vehicles today. One of the most striking aspects of operational criteria is that the payload criterion is rated at a relatively low level of importance. In general, studies and marketing activities are carried out on the delivery of small-sized cargoes in logistics operations with drones, but the demand for the transportation of heavy loads and thus a higher payload capacity has started to emerge in the market. However, the participants do not consider payload capacity as a criterion that is expected to make a significant difference in UAM logistics operations. Similarly, the camera and visual systems were rated as criteria with a low level of importance. In general, almost all the studies and related demonstrations on UAM and related aircraft include an integrated camera system on the aircraft. However, while this feature is probably more critical for other uses of drones, such as inspection, surveillance, and pesticide spraying, it is not considered to make a significant difference in logistics operations. Finally, the criterion of suitability for hazardous materials ranks last as the criterion with the lowest degree of importance, both in operational criteria and in all criteria in general. This can be considered as an expected result. Currently, even in the air cargo transportation market, the proportion of cargo carried within the scope of dangerous goods is limited, owing to various regulations and restrictions. Therefore, although it is an important area, it cannot be considered a priority area. This was reflected in the results of this study in a similar manner.

6 Conclusions

In the overall evaluation, when a total of 12 criteria under two main headings are evaluated together, safety, security, price, distance, and battery/energy performance are ranked as the top five criteria. Because safety and security are high-priority goals in aviation, price is always a highly sensitive criterion for stakeholders in the airline market, and distance and battery/energy performance are the first elements that come to mind for a system with drones, it is thought that the study reflects consistent results in general. In addition, the fact that the payload and speed criteria remain in the background of the ranking is the most surprising factor in terms of the results of the study. In contrast to these results, another study conducted with the UAL concept evaluated the weight of the cargo and time sensitivity as one of the key elements of the concept (Rifan et al., 2022). Building on the literature, this study similarly emphasises the importance of safety and security criteria but emphasises that there may be differences in the importance of criteria in each individual logistics operation.

The results reveal a set of key criteria necessary for the adoption of Factors Influencing UAV Selection in UALs. In terms of the contribution of the methodology, it contributes to the Methods section by using a relatively new MCDM methodology (FUCOM) to identify and evaluate the resulting criteria. No studies have been conducted in the field of FUCOM. Therefore, this study reveals the importance of the adoption of Factors Influencing UAV Selection in UALs as a phenomenon and contributes to the existing literature by identifying the relative importance of these factors to aid adoption. This study also contributes to the growing acceptance of FUCOM methodology in UALs studies. This also encourages the wider use of FUCOM-based methodologies in MCDM research in this sector. In general, this study contributes to the literature and industry by revealing the factors that are effective in aircraft selection criteria in UAM logistics operations or UAL systems in general. However, it is thought that conducting related research with different methods, criteria, participants, countries, and regions would be beneficial in terms of understanding aircraft expectations in the UAL system.

6.1 Theoretical and managerial implications

In urban logistics systems, factors such as the design of the distribution network, practicality, accessibility, and speed have begun to emerge, as well as the benefits of the use of UAVs. With the development and contribution of technology and knowledge in this field, examples of the use of UAVs in urban logistics deliveries have been observed. In this study, the importance of revealing the characteristics, qualities, or expectations of aircrafts for stakeholders who will use the relevant system has been realised. Undoubtedly, UAVs will operate in urban logistics systems over time. In the academic literature, many studies support the use of UAVs or drones in urban logistics systems (Jung and Kim, 2022; Toraman and Öz, 2023; Colajanni et al., 2023; Ezaki et al., 2024; Zieher et al., 2024; Rinaldi et al., 2024; Li, 2024; Dai et al., 2024). Although these studies generally address the UALs system and its operational processes, it is important to consider the technical characteristics of the aircraft, which is the most important element of the system.

At this point, managers who are stakeholders in the relevant system should not update their existing logistics distribution systems with UAVs late. However, during the update of the relevant system, it is important to consider the type of operation, characteristics of the region of operation, and UAV features as an intersection of consumer expectations. This adds value to the efficiency and sustainability of operations. At this point, in a market with dozens of different manufacturers, it should be one of the important tasks of managers to determine the most suitable aircraft for the needs and to include it in the system. It is also believed that the results of this study will contribute to this task. It is an opportunity to provide a general clue as to which elements should be used to meet the demand for the characteristics of the aircraft. On the other hand, the results of our study will also be beneficial for UAV manufacturers and managers in that field in terms of adding value to the process. In addition to the theoretical knowledge presented in our study and other similar studies in the literature, analysing the situation in UAV technology, which is currently being used in various operations in various regions, will provide another important practical value. Collecting feedback such as the contribution of the UAVs currently in the system to the operation, their deficiencies in the operation, and/or the consumer's satisfaction, demand, and expectations, and interpreting them by combining them with the theoretical results will be a responsibility that everyone can share in terms of the sustainability of the system.

6.2 Limitations and future scope

During the study, the novelty of the topic and difficulty of the applied methodology created various limitations. As the study is a new topic, the conceptual framework is not yet clear and different terminologies may be used in each study in the literature. Additionally, the fact that the UAM system is predominantly in the R&D phase can be conveyed as another important constraint. In this sense, while related studies in the literature are focused on either technical aspects or passenger acceptance, it has not been possible to compare and evaluate our study with others in this context. At the methodology stage, the fact that the system has not yet been fully commercialised and is widely available has led us to interview researchers rather than practitioners in this field while obtaining expert opinions. The small number of researchers in this field and their limited access to them created difficulties. In addition, participants' unfamiliarity with the method steps we used in the comparison of the criteria caused us to obtain invalid results, and we had to exclude participants from the study. As a result, the fact that the findings of the study address a relatively narrow and limited field of activity is a common impact limitation. The structure of this study may guide other researchers. In future studies, it is believed that new studies with an integrative approach to the entire logistics sector will contribute. Future researchers could also work from a sustainability perspective.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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