

A Survey: Typical Scenes and Corresponding Technology Challenges in UAM

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Abstract. Urban Air Mobility (UAM) is a new type of transportation delivery system based on highly automated drones operating at low altitude in urban or suburban areas. Aimed at finding out what directions current researches are focusing on and what directions can be considered as the future researches, this study integrates several papers about two typical scenes in UAM including air taxi and air emergency supplies delivery as well as three technological challenges in above scenes to find out what kind of directions are not mentioned. Firstly, we explain the definition of UAM and display a list of real cases of the current situation of UAM development. Secondly, researchers are focusing on the path optimization and single demand on the aircraft. However, they pay less attention on the interactions between the existing systems, and the supporting system also turned out to be a blank research direction. Thirdly, we mentioned three main technological challenges including battery problems, noise problems and non-GPS problems. Not only by giving the reason why those challenges came up, also scholars pointed out some feasible solutions. Finally, it's evidently that electric Vertical Take-Off and Landing technology (eVTOL) got a better develop in the UAM. However, researches about mating installations are a few by comparison. Opening up those potential factors in UAM can not only boost the whole system, also it can solve several technological problem.

Keywords: UAM; air taxi; air emergency supplies delivery; eVTOL.

1. Introduction

Urban traffic congestion and urban road capacity problems are constantly troubling transportation planners around the world, so it turned out that we tilted up our head to the sky and thought a brand new way of transportation, which is called Urban Air Mobility (UAM).

UAM, a new type of transportation delivery system based on highly automated drones operating at low altitude in urban or suburban areas, which includes a variety of vehicles, infrastructures, management rules, etc. After a similar concept was initially proposed by Uber in 2016 [1], it has caught a lot of attention, and in the 2018 NASA released a report on the market research [2] of urban air transportation, which complete the concept Uber has released and boosted the concept of UAM to another level. After that, countries have rolled into the field. As of today, 113 cities and regions in 55 countries/regions are developing electric Vertical Take-Off and Landing technology (eVTOL) and Advanced Air Mobility (AAM) services in just a few years. In the Asia-Pacific region, some preparatory works including policy introduction, and management system planning have already carried out in Japan, South Korea, India, Singapore, Australia and other countries on specific cities [3]. It was also pointed out that China is now constantly encouraging and promoting the development of urban low-altitude transportation [4]. The eVTOL in China has become a new force in the market. And as the first proponent of this Domain, the U.S. has fleshed out various details of this system over several years of iterative thinking, including airspace planning, technology iterations, and so on [5]. In North America, Monterrey (Mexico), Bellefonte (Pennsylvania), and Lincoln (Nebraska) have all pioneered UAM and AAM services in their respective regions (Philip Butterworth-Hayes). Not only in this case, major drone companies have also joined the eVTOL race track, Airbus, Boeing, Lilium Jet and other companies released a variety of prototypes. As the industry's leader, Yihang Company has vigorously reversed its research direction to urban air transportation since 2018, and ranks at the top of China's development progress of manned UAV, with its Yihang 216 and Yihang 116 having been put into the production line for manned flights. Although there are no mature examples at the moment, various evidences spring up frequently to show that the basic theories of UAM are

fundamentally complete, and it is able to conceptualize an UAM system exactly the way we suppose before.

It can be found that the existing researches on intra-city air transportation is more involved [6], but urban air transportation according to its transportation distance is generally classified as well as inter-city air transportation, this paper mainly discuss on intra-city air transportation.

The reminder of this paper is organized as follows. Section 2 presents two typical scenes of the UAM and displays several papers about how external factors affect UAM's operating, and some technological problems happen in those scenes are discussed in Section 3. Section 4 concludes the study and discuss future research directions.

2. Typical Scenes of UAM

UAM can be divided into two main types, which are passenger transportation and freight transportation. According to the objects to be transported, performances can be different. The following is an investigation of air taxi and emergency goods transportation scenarios.

2.1 Air Taxi

Passenger transportation demand is one of the main transportation needs of urban traffic, and it is also the core scene of urban transportation.

Urban air taxis have become one of the hottest topics at the moment thanks to the development of eVTOL, and there are many successful test cases. For example, the German company Volocopter completed the first flight demonstration of the Volocopter 2X air taxi in Seoul, South Korea in 2021. Some eVTOL vehicles are being tested by commercial companies for UAM [7]; Lilium Company has made no less than 25 related flights in 2021; American company Joby Aviation has also attempted about 10 flights in 2022.

In the initial design stage, many scholars aimed to verify the advantages and feasibility of air taxis compared with current ground transportation methods from the aspects of running time saving [8]. Compared to helicopters, eVTOLs are about 4 times faster [9] but only cost one-tenth [10]. Compared with the general vehicle in the ground traffic mode, its running time is also very significantly shortened. Haruki Long Ze et al. [11] studied the operation of air taxis in the same original place and destination compared with ground taxis under the premise of aircraft constraints. The final results show that air taxis save about 49 minutes of travel time compared with ground taxis in specific scenarios. Fischer et al. verified the possibility of time saving from the perspective of passenger demand [12], and the results also proved that air taxis save time compared to traditional ground transportation modes. This is also very consistent with people's initial expectations for this traffic mode, that is, to minimize traffic congestion and reduce travel time, and the reduction of running time also indirectly brings about excess fuel and operational cost savings, and more importantly, it has a significant effect on reducing CO₂ emissions to the atmosphere [13]. Some researchers [14] have used quasi-static simulation methods to test the energy consumption of air taxis and ground taxis under the premise of considering non-linear and aging effects and the partial load efficiency of engines and motors. If the current technology is adopted, electric air taxis have considerable advantages over hybrid ground taxis, especially in the case of low emission intensity of electricity production and penalty boundary conditions like congested traffic, aggressive driving styles and high loop factor values.

Scholars have also conducted research on the demand for air taxis. Suchithra Rajendran et al. [15] developed four machine learning models of multinomial logistic regression, artificial neural network, random forest, and gradient boosting method to predict the demand of air taxi users with a time saving of at least 40%. During the modeling process, they considered environmental factors such as travel OD points, temperature, and weather, as well as travel dates and time periods as factors affecting demand. Some scholars [16] use demand to determine the location distribution and quantity of UAV airports. For example, Landon C. Willey et al. used five heuristic algorithms to construct a

model for UAM air port selection; Akhouri Amitanand Sinha et al. [17] used a prescriptive analysis method to determine the infrastructure layout of air taxis in New York City. Different from the cluster analysis method widely used in the same field, they used a staged method to consider the location of air taxis under the influence of various potential demands .

According to my investigation, scholars' research on the demand for urban air taxis is divided into two parts, including how exogenous demand affects user travel and how exogenous demand will determine the location of its infrastructure. In particular, there have been many mature studies on the location of UAM operation stations. However, many researchers separate these two parts for research, but ignore that the location of UAM will also affect the travel demand of users to a certain extent. Therefore, the current report does not take into account the interaction of various parts in the entire system. The influence of user demand, which makes the UAM demand system not systematic.

It is worth mentioning that the definition of air public transportation in the urban air transportation system is not clear. NASA's report [5] defines the loads of air taxis and air buses as 1 to 5 people. The only characteristic that can distinguish the two is whether their trajectories are fixed. However, one of the remarkable characteristics of public transportation is that it has a large passenger load that other modes of transportation do not have. From this perspective, the term "air public transportation" seems inappropriate. This mode of operation is more like another form of air taxis. It is a special "air taxi" that operates on a fixed trajectory. It can be seen that there is still a brand-new developable model for air taxis. There are few articles on this model in the current research, and there is a lot of room for research on its service frequency, operating efficiency, channel planning and many other factors. Imagine an operation scenario in which air taxis and modular vehicles are combined. Its organizational form, path planning, and cost and time advantages compared with conventional air taxis can all be used as future research directions.

2.2 Air Emergency Supplies Delivery

A concept that is often mentioned in the scene of drone delivery of cargo is the "last mile". Due to technical limitations, drones have difficulties to cover the whole process of delivery, so they are often responsible for the end delivery of the "first mile" and "last mile". Under such a premise, UAV can be supposed to be the best role for the delivery of emergency supplies. Compared with other freight scenarios, the delivery of emergency supplies, especially medical supplies, provides a very friendly stage for drones.

Xunyi, a representative company in the commercial operation of domestic drone delivery, has delivered more than 30,000 kilometers in medical mileage [18]. And COVID-19 happened to show the ability of specific UAV like medical delivery drones. In 2020, SF Express drones delivered certain COVID-19 prevention supplies to Wuhan Jinyintan Hospital [19]; Novant has already delivered the first drone for COVID-19 prevention supplies like protective masks in 2020 [20]. Not only that, but in general disaster-stricken areas, UAV also plays an important role in delivery the emergency supplies. In 2018, JD.com deployed two Y3 cargo drones and two reconnaissance drones to the disaster-stricken areas of Xiwanzi Bridge in Miyun District and Liulimiao Town in Huairou District to assist in emergency material transportation and disaster area survey work. JD.com's drone transportation accounted for 30% of the supplies on the day [21].

Many scholars [22] have carried out researches on the distribution of urban nucleic acid testing samples under the influence of the COVID-19, using the Golden Eagle optimization algorithm (SGDCV-GEO) based on gradient optimization and Corsi changes to establish a path optimization model, and verify its applicability and effectiveness. There are also many scholars who are committed to building a UAV medical delivery system through modeling, and verifying its relative advantages in time through algorithms. For example, Xia Jing et al [23] established a complete UAV emergency blood dispatching system on the basis of a machine learning blood prediction model, and verified its effectiveness in urban scenarios through a simulation system. The results show that compared with the traditional mode, the drone delivery mode generally saves 11-32 minutes of waiting time under the premise of different numbers of patients. It has been effectively used and served 140 pre-hospital

severe trauma patients between 2022 and 2023. Sara Imran Khan et al. used capacitive vehicle routing problem (CVRP), particle swarm optimization (PSO), ant colony optimization (ACO) and genetic algorithm (GA) four heuristic algorithms to manage the path of medical drones. The results show that under the same traffic conditions, drones will reach their destinations in a shorter time than normal ambulances [24]. During the investigation process, it was found that in the scene of medical material distribution, UAV research is more concentrated on path planning and network construction, and there is a lack of research on the supporting infrastructure in the entire UAV operation system. Considering that cargo UAV are different from passenger UAV, their fuselage size and other factors allow them to design mobile airports. Therefore, considering the use of mobile vehicles as base stations will be a feasible research direction. In addition, the service scope of UAV delivery goods is limited by the current technology. Lu Ziyi et al. [25] considered a "free ride" UAV distribution mode, and built a model through a multi-UAV path search algorithm based on conflict avoidance. The final results show that this method really improves its service scope and the running time on the path is also shorter than the traditional operation method. Other researchers have found that if a medical delivery scenario is chosen, under certain circumstances, if the UAV is selected to run on an ambulance for a certain distance, and then the UAV is activated at a suitable location, the result of an increase in its operating efficiency will also be obtained in the end [23]. The unique conditions of cargo UAV make its organizational form more flexible. Similarly, there are considerable research gaps in the organization of UAV swarm collaborative operations. Scholars pay more attention to its organizational form, while ignoring its connection with supporting infrastructure. Considering the layout of its base stations will bring more development space for related research.

3. Technical Challenges in Specific Scenes

The above-mentioned studies are enough to show that there are some exist cases of UAM in real scenarios, but it is not difficult to find that the scenarios we're structuring today differs from the original definition of UAM. Nowadays, only the technical content of unmanned aerial vehicles has been completed, but complete system is no where to find. On the other hand, although the current unmanned aerial vehicle technology has been put into use, there are still many technical difficulties, which is also an important reason why some supporting facilities are difficult to implement in the future. The next part mainly explains the vital technical problems faced by drones from the perspective of battery technology, noise problems, and GPS technology.

3.1 Battery Problem

Almost all articles related to UAM will point out the battery problem, which is also one of the biggest technical problems in the current UAM scenes. The lack of drone battery technology makes it difficult for drones to be used for long-distance transportation, and even performs poorly in some urban transportation scenarios with complex paths. Moreover, battery trouble indirectly requires a higher demand for the base station equipment to support drones.

There is no doubt that the operation of UAV require a harsh demand on battery technology, and high-density batteries are necessary equipment [26]. Paper [27] have shown that the energy density of existing lithium batteries is about 1MJ/kg, while the energy density of aviation fuel exceeds 40MJ/kg. Under normal circumstances, if the battery is used as the energy source of the UAV, it will bring considerable volume to the UAV itself, which is contrary to the expected assumption of high power and small size.

However, if the battery performance enhanced, that would eventually expend the volume and quality of the battery, which will directly increase the flight burden of the UAV, also reducing the running time and flight distance of the UAV [28]. Taking the Liliun Jet battery as an example, the 240kg battery lasts for 55 minutes, and the battery accounts for about 49% of the total weight. It can be seen that the battery has technical difficulties in the ratio of power to volume, and the direction of future research will be high-performance compressed batteries.

Besides, some researchers have also put forward the assumption of using fuel cells to solve this situation, and the research results show that its transportation capacity is stronger than that of existing batteries [29]. It's evidently that there is considerable room for development of fuel cells. Under this premise, the development of clean energy has become the direction of future research. Of course, building an optimized model of the UAV charging path through modeling [30], [31] and using a charging car for wireless charging will also be a solution [32].

3.2 Noise Problem

Air taxis often bring a lot of noise during take-off and landing, which has a great impact on user acceptance. At the same time, the noise problem has become one of the main problems when UAM is successfully introduced [33]. Relevant scholars discussed the influence factors of propeller noise in UAV flight by using the number of UAV propeller blades, propeller pitch, and propeller diameter as independent variables to design experiments [34]. Eventually they proposed a theory that the interaction between propellers increases noise. Many related articles also conduct research on the issue of noise generated by UAV, and the research on noise generation of UAV is relatively mature.

What's more, Bauer, Michael et al. designed a semi-empirical experiment [35] to test the community noise generated by fixed-wing aircraft during descent and climb at vertical airports. They found that different paths and engine inclination angles may have an impact on the noise generated by the UAV. Based on this, they drew a noise footprint map around the take-off point to study the spatial distribution characteristics of UAV noise. So that they can take corresponding countermeasures. In addition, the regulation of UAV noise has also been put on the agenda, and Germany has proposed a method for UAM community noise identification [36]. Compared with the implementation of policies, UAV noise countermeasures are more like suggestions and theories, which means UAV noise is still an unresolved technical difficulty.

3.3 Non-GPS Problem

The operation of drones is inseparable from the service of GPS, but air traffic can be different from ground traffic, which is relatively mature in terms of GPS coverage. In some specific scenarios like indoor takeoff and landing of air taxis, asset tracking in warehouses, etc. where drones often face a non-GPS environment, some methods proposed in recent years like using visual positioning often relies on external conditions such as sufficient lighting [37], and there are uncertainties. At the same time, drones are vulnerable to GPS spoofing, which will increase the probability of drone mission failure. Some studies also show that cheaters tend to have a serious impact on drones [38]. However, with the advancement of current research, the ability of resisting GPS interference on UAV has gradually become stronger. In the research of M. Surendra Kumar et al., they found that the effectiveness of GPS attacks against commercial UAV is not as good as before, which means UAV already have corresponding resistance strategies [39].

However, it has to be admitted that the GPS navigation network of UAV still has defects, and UAV needs additional non-GPS navigation systems to operate under difficult conditions. For example, a group of domestic scholars has studied a positioning system based on WiGig beam fingerprints, which uses the cooperative work of transmitters and receivers to overcome the environment where UAV does not work with GPS [40]. In addition, the launch of the new concept of Space-Air-Ground Integrated Network (SAGIN) [41] is likely to change the pattern of global positioning networks, and the construction of a full-coverage navigation network will also be an effective strategy to solve the problem of UAV operating in a non-GPS environment.

4. Conclusion

This paper mainly investigates two typical scenarios of air taxi and medical emergency supplies UAV in UAM system, and finds some fatal technical difficulties from the scenarios, which includes battery capacity, UAV noise, UAV operation under non-GPS environment, etc.

Through research, the conceptual system proposed by UAM is relatively complete, in which the corresponding drone technology is relatively mature and can be initially applied to various scenarios, but there is no complete supporting facilities and relatively mature rule system to assist. Furthermore, the research direction is mostly on the optimization of intra-city paths and the influence of some exogenous factors on travel demand, but less consideration is given to the influence of the interactions between various subsystems in the whole system of UAM. At the same time, it is also found that the performance of the current UAM system is general when it exists alone, and it can not completely replace the existing ground transportation system. However, in the above scenarios, the use of ground-air hybrid mode will often be a great improvement in operational efficiency, so the hybrid mode of the UAM and the current ground transportation system is compatible with the mainstream of the next few years, and it is worthwhile to consider the short-term development direction of the cooperation with the existing ground transportation system. The challenges in technology are relatively difficult, and upgrading the technology level is the best way to solve the problem.

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