Research on Key Factors of Drone Delivery Services Demand

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Abstract. Drone delivery services have increasingly captured attention as society evolves. This study aims to explore the impact of perceived risks on the demand for drone delivery services. To investigate the key factors influencing the demand for these services, the study categorizes factors into five groups: human, drone, material, law, and environment, based on a comprehensive literature review. Through surveys and expert evaluations, the C-OWA method was employed to pinpoint the critical factors. The findings reveal that the cost of drone delivery, flight safety, and cargo security are the paramount factors affecting service demand. Delving deeper from a psychological perspective, it is found that customers' perceived risks associated with drone usage exert a foundational influence. By fostering a thorough understanding of drone delivery through public education, demonstrations, and hands-on experiences, it is possible to significantly mitigate potential customers' risk perceptions related to drone usage.

Keywords: Perceived Risk, Drone Delivery Services, Key factors, 4M1E, Combination Ordered Weighted Averaging

1 Introduction

In recent years, research, development, and commercial applications in the emerging field of drone logistics have seen a significant rise, particularly offering innovative solutions for parcel delivery and medical supplies transport [1]. Drones have demonstrated outstanding performance in the last-mile delivery sector [2]. Meituan, the China’s largest food delivery service and online-to-offline (O2O) local service provider, established in March 2010, who was listed on the Main Board of the Stock Exchange of Hong Kong since 2018 [3]. In 2017, Meituan embarked on exploring drone delivery services. By driving innovation in fulfillment tools and establishing a local instant delivery network with air-ground coordination, Meituan has elevated the efficiency and experience of urban instant delivery. By the end of August 2023, Meituan had completed the initial development of autonomous flying drones, intelligent dispatching systems, and efficient operational systems. Meituan has achieved normalized operations in seven business districts and along 17 routes in cities like Shenzhen and etc. Meituan can provide delivery services to users in 14 community office buildings and four 5A-level scenic spots. Public data indicates that as of November 2023, Meituan drones have

ICBBEM 2024, March 29-31, Wuhan, People's Republic of China

DOI 10.4108/eai.29-3-2024.2347463

landed on nearly 20 routes in Shenzhen City, covering 4 districts, with a total of approximately 210,000 delivery orders fulfilled.

The rapid growth of drone logistics can be largely attributed to the advantages brought about by the flexibility of drones. Drones can swiftly and flexibly transport goods to their designated destinations, effectively resolving the challenges associated with the final leg of traditional logistics [4]. In traditional logistics, the last mile of delivery often encounters various issues. Firstly, meeting customers' expectations for urgent delivery can be a challenge [5]. With major e-commerce platforms promising same-day, next-day, or even instant delivery, customers expect swift and convenient receipt of their purchases. While express delivery services are widely available, small businesses must strike a balance between meeting the demand for expedited delivery and ensuring cost-effective shipping rates. Secondly, manual delivery processes contribute to high costs for the final mile of delivery [6]. Lastly, most online shoppers anticipate free shipping when their purchases exceed a certain amount. However, delivery personnel are typically tasked with delivering numerous small packages to multiple locations, leading to increased fuel costs, and working hours for delivery companies, particularly exacerbated by inflation [7]. The rising demand for specialized consignment services also underscores a growing need for personalized delivery options. Additionally, complexities in last-mile logistics may arise due to factors such as unmanned signatures, rescheduled delivery times, and merchandise returns. On the other hand, drones offer a rapid and flexible solution to deliver goods to their destinations, effectively mitigating the challenges encountered in traditional last-mile logistics [8].

Drone Delivery Services (DDS) refers to the use of drones to provide applicable product delivery and transportation services based on consumer demand. Domestic and international research indicates that the current stage of research on DDS is becoming increasingly diverse. Scholars have studied the factors influencing consumers‘ choices of DDS from different perspectives. Parth Rameshbhai Gabani (2021) studied the logistics and supply chain operations in 20th-century India, and found that the new drones have influenced consumer groups, and the efficiency and cost of DDS have become fundamental reasons for consumers to choose drone services [9]. Le Yi Koh (2023) explored the potential factors influencing urban consumers' acceptance of DDS during the COVID-19. The study focused on issues such as user privacy concerns, subjective psychological willingness of users, and the efficiency of DDS affecting consumers' drone selection [10]. Evangelia Filiopoulou (2022) examined Greek consumers' preferences for DDS during the era of prevalent online shopping and indicated that the efficiency has become a key factor influencing people's choice of DDS [11]. Christian Nedu Osakwe (2022) discussed the importance of delivery risks for consumers when using DDS and highlighted that consumers decide whether to use DDS based on discrepancies between expected and actual costs, user privacy and security concerns, and the safety of goods [12]. Sreenivas Ewshwaroju (2020) researched a delivery system based on the Internet of Things using drones for delivery in the coming decades. The study suggested that consumer decisions on using drones depend on factors such as DDS efficiency and the security of information related to drone-delivered goods [13].

Research indicates that the investigation of factors influencing DDS is progressively advancing; however, there is a dearth of studies integrating specific consumer psychology research. In particular, the influence of perceived risk on DDS demand remains unclear. Therefore, this study aims to explore the impact of perceived risk on DDS demand through an analysis of key influencing factors. This article will comprise the following sections: Section 2 outlining the research methodologies, Section 3 presenting an analysis of critical influencing factors, and the discussing, and Section 4 providing conclusions and insights.

2 Methodology

To reveal the determinants of DDS demand, two distinct research methodologies were meticulously crafted: “Identifying the Set of Influencing Factors” and “Selecting Key Influencing Factors”, as depicted in Figure 1.

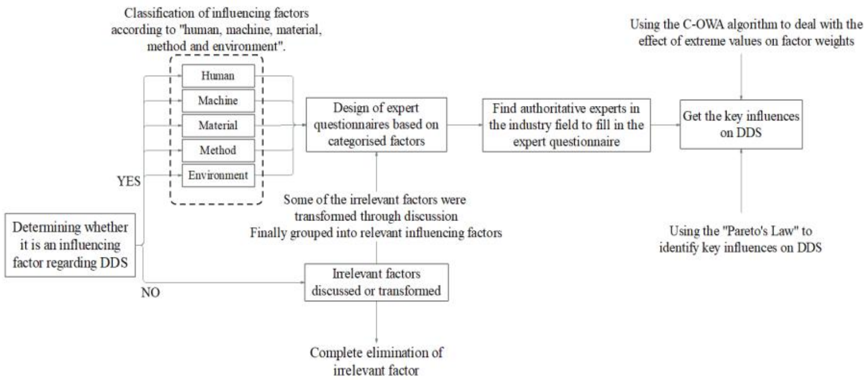

Fig. 1. Illustrates the flowchart of the research methodology.

First, ascertain whether the factors identified through the literature review method are relevant to DDS. If they are, categorize the influencing factors according to “human-drone-material-law-environment”; if not, exclude entirely irrelevant factors and integrate other adaptable factors into the relevant influencing factors set, while selecting a scoring method for these factors. Second, design expert questionnaires based on the influencing factors set, determine the required number of experts from relevant industry fields, and distribute as well as collect the expert questionnaires. Third, utilize the C-OWA algorithm to compute the weight of each influencing factor and rank them, leveraging the “80/20 rule” to identify the key influencing factors related to DDS.

The “4M1E” model, also referred to as “Man-Machine-Material-Method-Environment”, abbreviates the five main factors influencing product quality in Total Quality Management theory.

The expert rating method is a qualitative approach to quantitative assessment. It involves selecting specific evaluation criteria for the object under consideration, establishing evaluation standards for these criteria, and engaging representative experts to assess and provide scores for each criterion based on their experience.

The Combination Ordered Weighted Averaging (C-OWA) algorithm for Interval Combination Numbers is an algorithm used in the process of factor analysis.

(1) First, invite n experts to evaluate and score the index system of influencing factors according to their importance. When selecting experts for scoring, try to choose experts in the research field to make the scoring results more authoritative and scientific. Then distribute the survey questionnaire to create the original dataset.

(2) Set the original dataset as $A = \{a_1, a_2, \cdots, a_j, \cdots, a_n\}$ and processed in descending order from largest to smallest and renumbered starting from 0, the new dataset can be obtained as $B = \{b_0, b_1, \cdots, b_j, \cdots, b_{n-1}\}$, $b_0 \geq b_1 \geq b_2 \geq \cdots \geq b_j \geq \cdots \geq b_{n-1}$.

(3) The weight of b_j in dataset B is ϖ_{j+1}. It can be fixed by using the combinatorial number C_{n-1}^{j}, see equation (1). If the number of experts is n, and $\sum_{j=0}^{n-1} \varpi_{j+1} = 1$, then,

$$\varpi_{j+1} = \frac{C_{n-1}^{j}}{\sum_{j=0}^{n-1} C_{n-1}^{j}} = \frac{C_{n-1}^{j}}{2^{n-1}}, \quad (1)$$

where, C_{n-1}^{j} is the combinatorial number after selecting j data out of $n-1$ data, $j = 0,1,2,\cdots,n-1$ and $\varpi_{j+1} \in [0,1]$.

(4) By using the weights ϖ_{j+1} to dataset$B$, the absolute value weights $\widetilde{\varpi}$of each evaluation index can be obtained, as in equation (1).

$$\widetilde{\varpi_i} = \sum_{j=0}^{n-1} \varpi_{j+1} \times b_j, \quad (2)$$

where, $i = 0,1,2,\cdots,m$ and m denotes the number of indicator factors.

(5) The relative weight W_{b_i} of each index can be obtained by normalizing the absolute value weight of each index, as in equation (3):

$$W_{b_i} = \frac{\widetilde{\varpi_i}}{\sum_{i=1}^{m} \widetilde{\varpi_i}}, \quad (3)$$

where, $i = 0,1,2,\cdots,m$.

3 Key influencing factors

3.1 Factor Set

Through the review, we have summarized the influencing factors of DDS, with the main components outlined in Table 1.

Table 1. Summary of Factors Influencing Users' Choice of Drone Delivery.

Factor	Authors						
	Gabani [9]	Koh [10]	Filiopolu [11]	Osakwe [12]	Fang [14]	Yoo [15]	Balaban [16]
Customer's Expected Consumption Cost	—	—	—	√	—	—	—
Compatibility/Attitude towards Lifestyle	—	√	—	√	—	√	—
User Privacy and Security	—	√	—	√	—	√	—

Drone Load Capacity	—	—	—	—	√	—	—
Drone Delivery Efficiency	√	√	√	—	—	√	—
Drone Flight Safety	—	—	—	—	—	√	—
Drone Endurance	—	—	—	—	√	—	√
Cargo Safety	—	—	—	√	—	—	—
Drone Delivery Cost	√	—	—	—	—	√	√
Disposable Income of Residents	—	—	—	—	√	—	—
Total Amount of Social Consumer Goods	—	—	—	—	√	—	—
Weather Impact	—	—	—	—	—	√	—

As depicted in Table 1, the top three factors included “Drone delivery cost”, “Drone delivery efficiency”, and “Lifestyle compatibility/attitude”. By categorizing these 13 factors into five dimensions using “4M1E”, a factor classification relationship tree diagram can be generated, as illustrated in Figure 2.

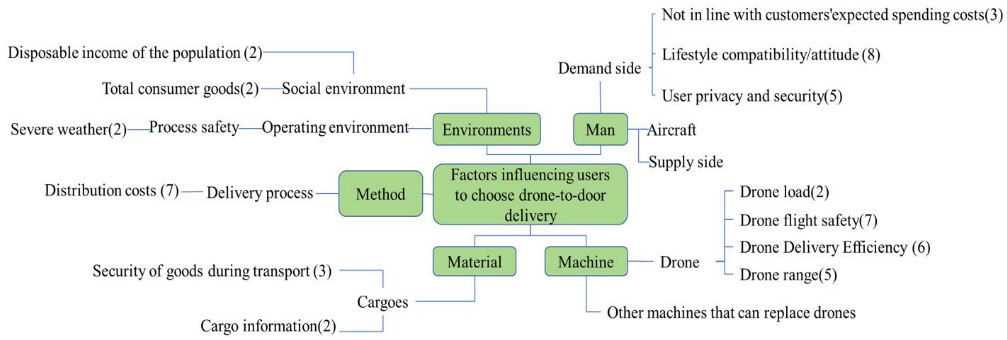

Fig. 2. Tree Diagram of Factors Influencing Users' Choice of Drone Delivery.

3.2 Data Source

Data Collection Method Used. After carefully considering the research objectives and feasibility, and thoroughly understanding the applicable conditions and characteristics of analysis methods such as on-site observation, questionnaire surveys, interviews, and symposium discussions, we ultimately opted for the “questionnaire survey method” to collect data online and conduct analysis.

Following the six-step process of “identifying research questions - sampling and designing surveys - implementing survey procedures - data processing and analysis - writing questionnaire survey reports - summarizing and evaluating”, we designed a questionnaire and distributed it to 12 relevant experts for investigation. The questionnaire comprises three sections. Firstly, an explanation of the questionnaire's purpose. The introduction includes salutations, the investigator's details, research objectives, and the survey topic. Secondly, basic information about the experts, including gender, years of experience, local climate characteristics, research fields, etc., which will be used for questionnaire screening and assessing the data's reliability. Thirdly, an investigation into influencing factors. This section assigns a score range of 0-10 based on 13 factors extracted from the literature review, where higher scores indicate a greater perceived impact by experts.

To assess the reliability and validity of the data obtained from the expert questionnaire, reliability refers to the degree of consistency in measurement data. It indicates the extent to which repeated measurements of the same objects using the same method can reflect consistent results. The Cronbach's alpha coefficient is employed to conduct a consistency test on the scale. The formula for calculating Cronbach's alpha is as in equation (4).

$$a = \frac{K}{K-1}\left(1 - \frac{\sum S_x^2}{S_i^2}\right) \tag{4}$$

where, a is the reliability coefficient, $K$is the number of test questions, S_i^2represents the score variation of all subjects on the i^{th}question, S_x^2 is the variance of the total score obtained by all subjects.

The scale-level Content Validity Index (S-CVI) for the scale was calculated to be 0.72, indicating a good content validity of the entire scale. It has been verified that the data obtained from this questionnaire pass the reliability test, indicating that the collected data are of good reliability and can be further analyzed empirically. Then, the weights of each influencing factor were calculated using the C-OWA algorithm.

3.3 Key Factors

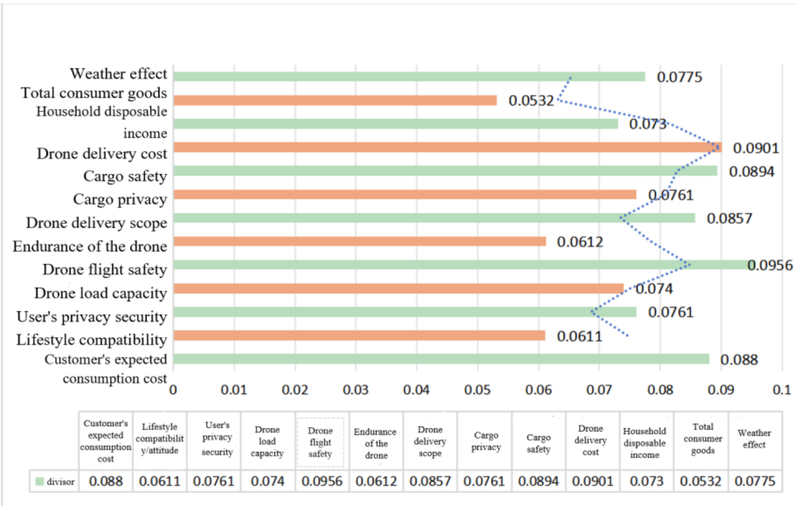

Fig. 3. Weights of influencing factors.

Figure 3 depicts the weight distribution of influencing factors based on the computational results. In the illustration, the weight assigned to weather impact is 0.0775, total social consumption stands at 0.0523, residents' disposable income holds a weight of 0.073, drone delivery cost is weighted at 0.0901, goods safety at 0.0894, goods privacy at 0.0761, drone delivery range at 0.0857, drone endurance at 0.0612, drone flight safety at 0.0956, drone payload capacity at 0.074, user privacy and security at 0.07661, lifestyle compatibility/attitude at 0.0611, and customer anticipated consumption cost at 0.088. By organizing the factor weights in descending order and adhering to the Pareto principle, the top three influential factors are identified as “drone flight safety”, “drone delivery cost”, and “goods safety”, crucial in impacting consumer preference for drone delivery services.

This is consistent with the findings of related studies. Yoo, Wonsang (2018) found that the main factors influencing drone delivery are safety and costs [15]. Mohsan (2022) found that factors hindering the development of drone delivery include drone delivery costs, drone delivery range, drone flight safety, and drone endurance capabilities [17].

4 Conclusion

This study delved into the factors impacting Drone Delivery Services (DDS) through a multi-layered analysis employing various methods. Ultimately, three key factors affecting DDS were identified: drone delivery costs, flight safety, and cargo security. The study revealed that consumer choices influencing last-mile drone delivery are influenced by consumers' perception of risks. When appropriate strategies are employed to reduce perceived risks, consumers' purchase desire increases, leading to higher demand.

Therefore, it is the evident that efforts to increase DDS demand should focus on reducing consumers' perceived risks. Factors influencing consumers' choices for last-mile drone delivery vary in importance depending on the environmental context and other aspects of the consumers' location. Pilot projects should be implemented in different regions to conduct relevant research on last-mile drone delivery and derive more measures to reduce perceived risks.

Acknowledgments. This work was partially supported by the University Students Innovation and Entrepreneurship Project of Tianjin, grant number 202310059069. Thanks a lot for the technical supporting from Danyang SHEN, associated professor from School of Transportation Science and Engineering, Civil Aviation University of China.

References

[1] Euchi, Jalel.: Do drones have a realistic place in a pandemic fight for delivering medical supplies in healthcare systems problems? Chinese Journal of Aeronautics. pp. 182-190 (2021)

[2] Borghetti, Fabio, et al.: The use of drones for last-mile delivery: A numerical case study in Milan, Italy. Sustainability. pp. 1766 (2022)

[3] Zhang, Marina Yue, and Peter Williamson.: The emergence of multiplatform ecosystems: insights from China's mobile payments system in overcoming bottlenecks to reach the mass market. Technological Forecasting and Social Change. pp. 121128 (2021)

[4] Azmat, Muhammad, and Sebastian Kummer.: Potential applications of unmanned ground and aerial vehicles to mitigate challenges of transport and logistics-related critical success factors in the humanitarian supply chain. Asian journal of sustainability and social responsibility. pp. 1-22 (2020)

[5] Xu, Mark, Brett Ferrand, and Martyn Roberts.: The last mile of e-commerce–unattended delivery from the consumers and eTailers' perspectives. International Journal of Electronic Marketing and Retailing. pp. 20-38 (2018)
[6] Hübner, Alexander Hermann, Heinrich Kuhn, and Johannes Wollenburg.: Last mile fulfilment and distribution in omni-channel grocery retailing: a strategic planning framework. International Journal of Retail & Distribution Management. pp. 44.3 (2016)
[7] Cramer, F. and Fikar, C.: Investigating crowd logistics platform operations for local food distribution", International Journal of Retail & Distribution Management. pp. ahead-of-print (2023)
[8] Jazairy, A., Persson, E., Brho, M., von Haartman, R. and Hilletofth, P.: Drones in last-mile delivery: a systematic literature review from a logistics management perspective. The International Journal of Logistics Management. pp. ahead-of-print (2024)
[9] Gabani, Parth Rameshbhai, et al.: A viability study using conceptual models for last mile drone logistics operations in populated urban cities of India. IET Collaborative Intelligent Manufacturing. pp. 262-272 (2021)
[10] Koh, Le Yi, et al.: Urban drone adoption: Addressing technological, privacy and task–technology fit concerns. Technology in Society. pp. 102203 (2023)
[11] Filiopoulou, Evangelia, et al.: Last-Mile Delivery Options: Exploring Customer Preferences and Challenges. In Proceedings of the 2022 17th International Workshop on Semantic and Social Media Adaptation & Personalization (SMAP), Corfu, Greece, 3-4 Nov. (2022)
[12] Osakwe, Christian Nedu, et al.: Critical factors characterizing consumers' intentions to use drones for last-mile delivery: Does delivery risk matter? Journal of retailing and consumer services. pp. 102865 (2022)
[13] Eeshwaroju, Sreenivas, Praveena Jakkula, and Iheb Abdellatif.: An IoT based Three-Dimensional Dynamic Drone Delivery (3D 4) System. In Proceedings of the 2020 IEEE Cloud Summit, Harrisburg, PA, USA, 21-22 October (2020)
[14] Fang, Zhang, and Zhang Hong-Hai.: A method for "last mile" distribution demand for drones. In Proceedings of the 2020 IEEE 5th International Conference on Intelligent Transportation Engineering (ICITE), Beijing, China, 11-13 September (2020)
[15] Yoo, Wonsang, Eun Yu, and Jaemin Jung.: Drone delivery: Factors affecting the public's attitude and intention to adopt. Telematics and Informatics. pp. 1687-1700 (2018)
[16] Balaban, Mariusz A., Thomas W. Mastaglio, and Christopher J. Lynch.: Analysis of future UAS-based delivery. In Proceedings of the 2016 Winter Simulation Conference (WSC), Washington, DC, USA, 19 January (2017)
[17] Mohsan, Syed Agha Hassnain, et al.: Towards the unmanned aerial vehicles (UAVs): A comprehensive review. Drones. pp. 147 (2022)